Journal of Experimental Psychology

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OPERANT CONDITIONING, EXTINCTION, AND PERIODIC REINFORCEMENT IN RELATION TO CONCENTRATION OF SUCROSE USED AS REINFORCING AGENT[1]

NORMAN GUTTMAN

Indiana University[2]

This study deals with the effects of using various concentrations of sucrose as reinforcing agent in the bar-pressing situation. The processes investigated include conditioning, extinction, and reconditioning under continuous reinforcement and performance under periodic reinforcement (PR). The same *S*s and apparatus are used throughout the series of experiments so that the findings may possess some degree of quantitative comparability.

In the investigation of the "quantity of reinforcing agent," the technique of manipulating the concentration of a soluble nutrient has distinct advantages. Previous studies which have demonstrated a relationship between the amount of food given as reinforcement and the degree to which response characteristics are changed by reinforcement have used the following methods for controlling the amount of food presented on a given trial: (*a*) single food particles of various weights or sizes (**4, 5, 10, 13, 14, 15, 21, 23**); (*b*) various numbers of food particles of equal size and weight (**1, 6, 10, 14, 21**); and (*c*) exposure to food for various lengths of time (**9**).

These methods may not be equivalent, and none is satisfactory from an analytical standpoint, since they all introduce several simultaneous sources of variation. If quantity of food is varied by the conventional methods, concurrent changes may be produced in the following factors: (*a*) the amount of nutrient available for assimilation, in terms of weight, volume, or some nutritive unit; (*b*) the amount of consummatory activity required, i.e., the number and intensity of ingestive movements at each reinforcement; (*c*) the stimulation (visual, olfactory, tactile) derived from the food prior to ingestion; and (*d*) the stimulation from the food during ingestion.

If we vary the size or number of pieces of food given to an animal, we are varying at once the stimuli which affect its receptors, the amount of chewing and swallowing it performs, and the degree to which its metabolic state will be affected (at some later time). Methods *a* and *b* involve

[1] Based on the author's doctoral dissertation at Indiana University. Dr. W. K. Estes sponsored and greatly aided this research.

[2] Now at Duke University.

changes in all four of the above factors. Method *c* affords some control of the third and fourth factors, but even here, duration of stimulation varies along with the first and second factors.

The technique of manipulating sucrose concentration reduces the multiplicity of the variable "quantity of reinforcing agent." It controls stimulation prior to ingestion and reduces variation in required ingestive activity. It does not avoid a covariation (although presumably not a linear one) between nutritive value and stimulation at the taste receptors. Nonetheless, if relations are found between concentration and various aspects of behavior, such relations can be presumed independent of stimulation prior to ingestion, and the analysis of such relations may be focused on a more restricted set of events, those during and subsequent to ingestion.

If the stimulational aspects of the reinforcing agent are of importance, the use of a concentration scale provides a more rational metric for the scaling of gustatory stimuli than is permitted by such units as weight, volume, or number of solid food particles. Since concentration is a significant and familiar dimension of stimuli in sensory research, analysis of the mechanisms involved in reinforcement may be facilitated by being brought into relation with extant knowledge of receptor processes. Such analyses may be promoted by the additional device of using simple substances of known chemical composition, such as sucrose, about which much relevant information is already available from studies of various aspects of taste (**12**), as well as from research in food acceptance (**22**) and nutrition. The present experiments are designed to narrow the gap between the findings in these areas and that group of experiments grounded rather exclusively in contemporary theories of learning.

Method

Apparatus

A set of four identically constructed Skinner boxes was used(**7**). The *S* was housed in a sheet metal box into which a bar could be inserted. This box was housed in a larger semi-soundproof chamber with an observation window. The liquid used as reinforcement was presented to *S* by a dipper-type magazine driven by a motor. The volume of liquid presented by the dipper was of the order of .005 milliliter. A manual switch controlling the magazine was mounted outside the box, and used only in training *S* to drink from the dipper. The bar-pressing response was recorded by means of a magnetic counter and also by means of a graphic recorder which made a cumulative plot of responses against time.

Subjects

The *S*s were 80 male albino rats, ranging in age from 64 to 110 days at the start of the experiment. They were run in five successive sets of 16. Two *S*s in the last set died and one became ill during the experiment, but these *S*s were not replaced by others.

Procedure

Basic design.—The *S*s were assigned to four experimental groups. Treatment of the groups was identical except for the concentration of sucrose used as reinforcing agent. The four concentrations were 4%, 8%, 16%, and 32% sucrose by weight,[3] and each group was designated by the concentration received. Each group received a single concentration throughout training, except during the last portion of the experiment in which certain *S*s from each group were tested on all four concentrations.

Habituation and feeding schedule.—Upon receipt from the supplier, *S*s were placed in individual living cages and fed dry Purina pellets ad libitum for at least one day. All food was then withdrawn for 23 hr. For a minimum of three successive days, *S*s were given a firm mash

[3] For example, the 32% solution was prepared by mixing 32 gm. of commercial granulated table sugar with 68 ml. of tap water. The four concentrations have the values .6, .9, 1.2, and 1.5 on a log 10 scale, and this scale is used in the graphs which follow.

of ground Purina pellets for 1 hr. per day at the experimental time. Cod-liver oil was occasionally added to the mash. During feeding, *Ss* were picked up and handled. During all phases of the study, *Ss* were fed mash for 1 hr. following the experimental period, and water was available at all times in the living cages.

Magazine training.—The *S* was introduced into the box and trained to approach the magazine whenever it was operated by *E*. The bar was retracted from the box, and the magazine was filled with the appropriate sucrose solution. All sessions were ½ hr. in length.

The magazine was operated only a few times on the first day to facilitate habituation to the rather loud noise and the slight vibration produced by the operation of the magazine. On subsequent days the magazine was operated at irregular intervals until *S* had responded 8 to 10 times by approaching and drinking from the dipper. A completed training trial was recorded when *S* approached and drank within 30 sec. of the operation of the magazine. Magazine training was continued the number of days required for the *S* to accept 50 magazine presentations.

Any *S* that failed to accept more than five presentations within ten days was discarded, but this criterion was imposed in only three cases. Certain *Ss*, especially in the 4% and 8% groups, did not always drink after approaching the magazine; only those approaches which were followed by prolonged contact with the dipper or by the characteristic head-bobbing movements accompanying licking were counted as accepted presentations. The magazine was generally operated only when *S* was moving about the cage, to insure that the response of huddling near the magazine not be reinforced, and thus impede the subsequent conditioning of bar-pressing.

Conditioning of the bar-pressing response.—On the day following the completion of magazine training, conditioning was begun. The bar was inserted into the box and set to operate the magazine with each depression. The *S* was permitted to obtain 250 reinforcements for bar-pressing and then was removed from the box. (It was sometimes impossible to remove the animal precisely after Response 250 if it was responding at a high rate.) On the next day, 250 more reinforcements were given. Five 4% *Ss* that failed to obtain more than 25 reinforcements in ten days were discarded.

Animals that were slow to respond to the bar were kept in the box a minimum of 30 min. a day and were not removed until a 15-min. period of no responding had elapsed. In general *Ss* that responded so slowly that 250 reinforcements were not obtained in one hour were removed at 1 hr. However, several of the first cases of this type were left in the box for arbitrary times beyond 1 hr. in order not to interrupt the course of conditioning. After these cases, a sufficient number of 1-hr. periods was given to permit the execution of a total of 500 responses.

Extinction.—On the day following the completion of conditioning, extinction of the bar-pressing response was carried out under two conditions, first without secondary reinforcement and then with secondary reinforcement. Before *S* was placed in the box, the bar was inserted, the magazine was emptied of sucrose solution, and the dippers were washed and dried. The *S* was placed in the box, and for 5 min. following the first response, all bar-pressing responses were recorded but not reinforced. At the end of the 5-min. period, the apparatus was set to operate the empty magazine after each bar-depression. Thus, each bar-pressing response was followed by the stimulus that had previously accompanied the delivery of sucrose solution of a given concentration. The *S* was removed from the box 30 min. after the first response that received secondary reinforcement. One *S* failed to respond after the first 5-min. period and was removed from the box after a 40-min. period of no responding.

Reconditioning.—On the day following extinction, *S* was subjected to the same conditions (including sucrose concentration) which had prevailed during original conditioning and was permitted to obtain 250 reinforcements for bar-pressing. Failure to recondition promptly and obtain 250 reinforcements was exceptional, but *Ss* that were removed from the box before obtaining 250 reinforcements were given as many periods as required to obtain this total, the same conditions prevailing each day. Five *Ss* required more than one day to complete reconditioning.

Periodic reinforcement.—Two determinations of the effect of sucrose concentration on the rate of the periodically reinforced bar-pressing response were carried out. The first was a comparison of four independent groups each receiving a single concentration. Each *S* received the same concentration as that received during previous training. The second determination involved testing each *S* repeatedly on all of the four concentrations previously used.

PR: Independent groups.—The *Ss* in all four groups were given five successive daily ½-hr. experimental periods in the Skinner boxes of periodic reinforcement for bar-pressing. The first day of PR followed the last day of reconditioning under continuous reinforcement. The PR interval was 1 min., i.e., only the first bar-pressing response in each minute was reinforced, but all responses were recorded. Complete data were obtained on 42 *Ss* in this portion of the experiment.

PR: Each animal as its own control.—Following the completion of the above procedure, *Ss*

were given a series of 12 successive daily 1-hr. sessions of bar-pressing under PR. Each day each *S* received one 15-min. test on each of the four concentrations previously given. The same 1-min. PR schedule was maintained.

The order of presentation of concentrations was counterbalanced, such that within the first four days each *S* received each concentration once during the first 15-min. test interval, once during the second 15-min. interval, and so on. The order of presentation during Days 1 to 4 was repeated during Days 5 to 8 and repeated again during Days 9 to 12.

The *S*s were generally run in squads of four in this procedure. On a given day each Skinner box contained one concentration, but during each four-day cycle each box contained each solution once, to control for variability among boxes. To begin a daily session, four *S*s were placed in the boxes with the main switch of the apparatus turned off. The boxes were closed, and the switch was turned on and left on for 15 min. while *S*s responded. Then the switch was turned off, *S*s were quickly transferred to other boxes and other concentrations, and another 15-min. period was begun. Twenty *S*s were used in this part of the experiment. These 20 *S*s comprise 3 from the 4% group, 6 from the 8% group, 6 from the 16% group, and 5 from the 32% group.

Results

Time to condition.—The effect of concentration of reinforcement on the time required to condition the bar-pressing response is a very striking one. The median number of experimental periods required to obtain the 500 reinforcements (counting from the period in which the first response occurred) was 2.0 for the 32% and 16% groups, 3.5 for the 8% group, and 6.5 for the 4% group. Five of the 18 *S*s in the 4% group failed to condition to the bar within the ten-period criterion, but all other *S*s that completed magazine training were successfully conditioned. Table 1 shows the mean times required by the various groups to complete the first and second 250 responses. Both the means and *SD*'s are clearly affected by concentration. The differences between pairs of groups with respect to time to obtain the first 250 reinforcements are (with the exception of the difference between the 8% and 16% groups) statistically significant at or beyond the 5% level of confidence.[4] For the second 250 reinforcements the differences among groups are smaller, and only the differences between the 4% group and each of the others are statistically significant. As will be seen in detail below, the 16% group obtains the second 250 reinforcements in the shortest time.

TABLE 1

Mean Time in Minutes to Obtain First and Second 250 Reinforcements with Various Sucrose Concentrations

Sucrose Concentration	*N*	Reinforcements			
		1–250		251–500	
		Mean	*SD*	Mean	*SD*
4%	11	252.8	108.4	87.6	55.0
8%	15	118.7	92.0	31.8	25.1
16%	16	71.1	60.4	21.2	9.8
32%	17	36.5	10.4	23.8	10.1

Inspection of the cumulative records obtained during conditioning reveals certain important points. Only in the 32% group do all *S*s show the kind of conditioning curve that has ordinarily been obtained in the Skinner box with water or food pellets as reinforcement. In this group the first or second response is followed in the succeeding few minutes by a sustained acceleration to a high and stable rate. Most records in the 16% group are quite similar, but in a few cases the acceleration does not develop until 5–10 reinforcements have been obtained.

In the 8% group, only 4 of the 15 complete records are "typical." In the other cases, the acceleration to the

[4] The heterogeneity of the variances precludes the use of the analysis of variance. Therefore, the Festinger (3) and Mann-Whitney (11) tests have been used. The latter test was used for those values of *N* for which the Festinger test is not tabled.

final rate is very protracted, extending over as many as three or four experimental periods. The responses occur in definite bursts, separated by pauses ranging from seconds to several minutes. In the 4% group, no typical records are found, and the features seen in the 8% records are exaggerated. A steady rate of responding may not be achieved within 500 reinforcements. As conditioning progresses, the number of responses in a burst tends to increase. Within a burst, the rate of responding may reach 25 per minute, which is approximately as great as that observed in any *S*.

Changes in rate during conditioning.—The graphic cumulative records were averaged by obtaining from each record the time required for successive blocks of reinforcements and converting these times to rates of responding. The averaged conditioning curves (group mean rate as a function of number of reinforcements) are shown in Fig. 1. Primarily, it may be seen

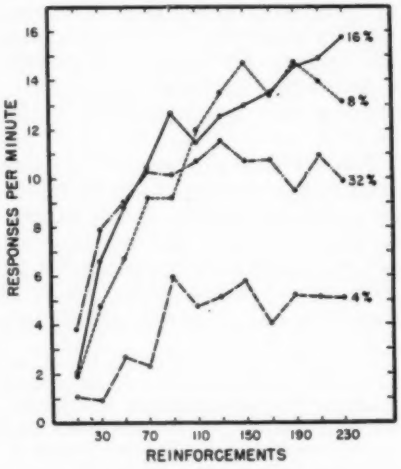

FIG. 1. Mean rate of bar-pressing of groups receiving various sucrose concentrations over the course of the first 240 continuous reinforcements

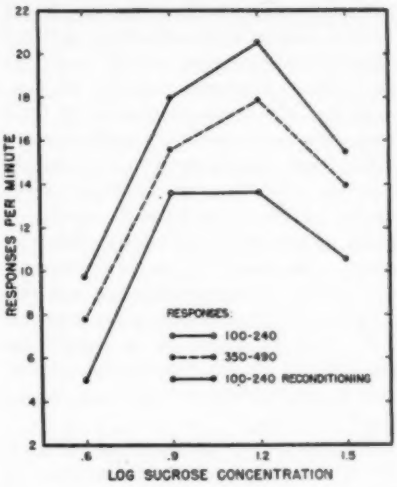

FIG. 2. Mean rate of bar-pressing under continuous reinforcement as a function of sucrose concentration at three stages of training

that for the first 50 responses the curves are ranked in ascending order according to concentration. Beyond this point the rate of the 32% group is surpassed by that of the 16% group and later by that of the 8% group. The corresponding curves for the second 250 reinforcements and for reconditioning are essentially similar.

Final rate of responding under continuous reinforcement.—Estimates of the asymptotic rates of responding for the various groups were obtained by taking the mean rates over the following blocks of reinforcements: (*a*) from Reinforcements 100 to 240; (*b*) from Reinforcements 350 to 490; and (*c*) from Reinforcements 100 to 240 of reconditioning.[5] These final rates are plotted against log concentration in Fig. 2. The three curves are clearly of similar form and are successively dis-

[5] In general these blocks of reinforcements are the latter portions of given experimental periods, but for certain 4% and 8% *S*s these blocks may comprise several periods.

placed upward on the ordinate. Final rate of responding increases as a function of concentration to 16% and then decreases. Separate analyses of variance for the three estimates of final rate were performed. In each case the differences among groups are significant beyond the .1% level of confidence. Differences between means of pairs of groups were tested with the *t* test. All comparisons involving the 4% group are significant beyond the .1% level. The difference between the 16% and 32% groups is significant beyond the 1% level in two instances, and it approaches the 5% level in the third instance.

Resistance to extinction.—In Fig. 3 are shown the mean extinction curves for the various groups. The initial points on these curves, representing 5 min. of extinction without secondary reinforcement, are ranked in ascending order according to concentration. These points are plotted as a function of concentration in the lower curve of Fig. 4. The differences among the groups are significant, in terms of the analysis of variance, beyond the 1% level of confidence. In terms of the *t* test, all differences between nonadjacent pairs of groups are significant beyond the 2% level.

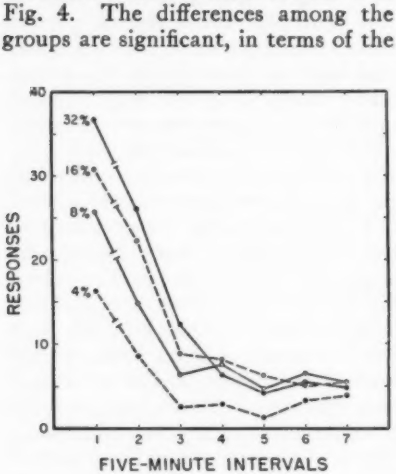

FIG. 3. Extinction curves for groups previously trained under continuous reinforcement with various concentrations. During the final 30 min., bar-pressing was followed by the sound of the magazine.

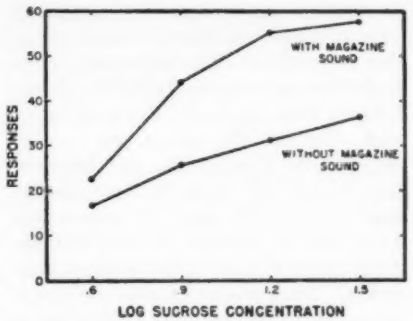

FIG. 4. Resistance to extinction as a function of sucrose concentration previously received

For at least the first 10 min. of the second phase of extinction, the groups are again ranked according to concentration. Beyond this point several inversions appear. The total number of responses in the second phase is plotted as a function of concentration in the upper curve of Fig. 4. The relationship is monotonic, but curvilinear. The analysis of variance for the totals indicates that the between-groups differences are not significant ($p(F) > .10$).[6]

PR: Independent groups.—The mean rates of bar-pressing of the four concentration groups for all five experimental days are plotted as a function of $\log_{10}$ sucrose concentration in Fig. 5. Rate of responding under PR is a monotonic increasing function of con-

[6] A sampling error involving the loss of one case qualifies the findings for the second phase of extinction. The largest extinction curve for this phase (323 responses) was obtained from a 32% *S* whose results are not included because it received six presentations of 8% sucrose by mistake during magazine training. Inclusion of this case would cause the mean extinction curve for the 32% group (Fig. 3) to be highest at all points.

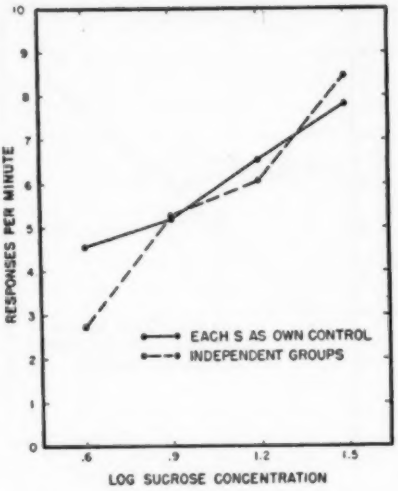

FIG. 5. Mean rate of bar-pressing under periodic reinforcement

centration over the range from 4% to 32% sucrose. The rate of the 32% group is more than triple that of the 4% group. In terms of the analysis of variance the over-all differences are significant beyond the .1% level of confidence. In terms of the *t* test the differences between mean rates of pairs of groups are (with the exception of the difference between the 8% and 16% groups) significant at the 5% level, or better.

PR: Each animal as its own control.—The over-all relation between concentration and rate of responding in this determination is shown in Fig. 5. The empirical function is again nearly logarithmic, but the range of differences is more restricted than in the preceding determination. A statistical test of the differences among concentrations in terms of the analysis of variance indicates that the differences are significant beyond the .1% level of confidence. The *t* tests of differences between means of pairs of concentrations are significant beyond the .1% level in all instances.

The average relationship for this determination is supported by the findings for individual *Ss*. In general, the rate-concentration curves for individual *Ss* are of the same monotonic increasing form as the mean curve, 16 of the 20 *Ss* showing no inversions. The differences among the individual curves are mainly in respect to their slopes and placements.

There is no indication that the concentration used in conditioning or prior PR training has a significant effect upon the results of the present determination. Rate-concentration curves were obtained for the four subgroups which were trained on different concentrations prior to this part of the experiment. These subgroup curves lie within .6 of a response per minute of the mean curve for the entire group of 20 *Ss*. A statistical test of the differences among the subgroup curves by means of the multivariate analysis of variance reveals differences at the 38% level of confidence.[7] The degree of similarity of the subgroup curves is striking in view of the small numbers of *Ss* involved.

Comparison of the two PR procedures.—The quantitative disparity between the relationships shown in Fig. 5 is reduced when an estimate of the asymptotic rate-concentration function from the second determination is obtained. Over the 12 days of this experiment, the differences in rate among concentrations increase, the major portion of the change occurring in the first four days. During the course of the 15-min. experimental periods, the rates on various concen-

[7] Thanks are due to Dr. C. J. Burke for the suggestion that the multivariate form of the analysis of variance would be appropriate here and for the computation of the distribution function of the statistic for the parameters occurring in this application.

trations diverge as shown in Fig. 6. Estimates of the asymptotic rates for the second PR determination were derived by taking mean rates from the last 5 min. of test intervals in the last eight experimental days, when both long- and short-term changes are proceeding slowly. These values are plotted in Fig. 7, along with mean rates from the entire independent groups experiment. Straight lines have been fitted to these two sets of values by the method of least squares. The empirical points and fitted lines coincide to a marked extent, indicating a high order of stability in the underlying function. Also, it may be seen that the PR values are in agreement with the mean rates of responding for the first 5 min. of extinction following continuous reinforcement. This relationship is somewhat in accordance with Skinner's notion of the "extinction ratio." Of course, the agreement of the PR and extinction values depends upon the portion of the extinction process which has been considered in the comparison, since in extinction all rates eventually go nearly to zero.

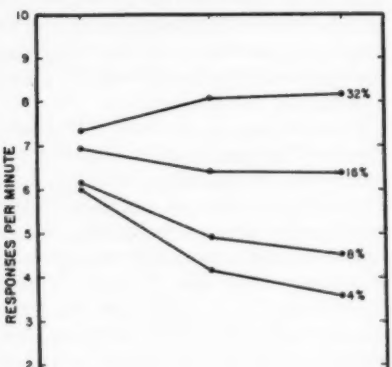

FIG. 6. Changes in rate of responding under PR during successive thirds of 15-min. test intervals. Each point is the mean of 240 5-min. intervals.

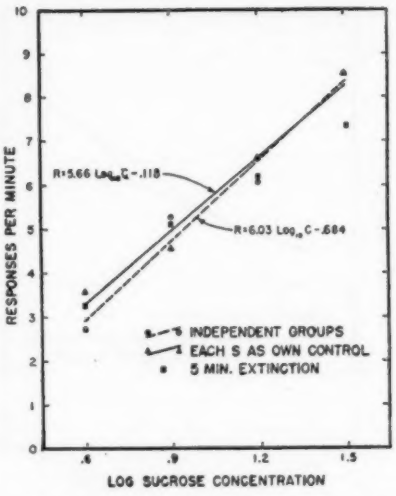

FIG. 7. Fitted rate-concentration functions for the two PR determinations. Mean rates of responding during first 5 min. of extinction following continuous reinforcement are replotted here for comparison.

Reinforcement threshold for sucrose.— The equations in Fig. 7 permit an estimate of the highest concentration of sucrose for which the rate of responding would not be expected to exceed the unconditioned rate, or operant level (**17**). This may be done by setting the equations equal to the operant level and solving for concentration. In this situation the operant level is not greatly in excess of zero, so as an approximation this value has been used. The two equations then yield 1% and 1.3% sucrose concentration as estimates of the reinforcement threshold. These values are of the same order of magnitude as the rat's sucrose taste threshold, .5% concentration, as determined by the preference method (**16,22**). What importance can be attached to these findings we shall discuss below.

Discussion

The concentration of sucrose used as reinforcement for bar-pressing has considerable effect upon acquisition, resistance to extinction, and performance under both continuous and periodic reinforcement. In general, the effects of concentration over the range investigated take the form of monotonic increasing functions. The exception is the case of final rate of responding under continuous reinforcement, where a consistently nonmonotonic relation to concentration is found. No satisfactory account of this relation can be given here, but various hypotheses need to be considered, and comparison must be made between other of the present findings and the results of previous experiments concerned with magnitude of reinforcing agent.

Acquisition.—The present acquisition curves do not confirm Hull's view (**8**) and Zeaman's finding (**23**) that the number of reinforcements required to reach the performance asymptote is constant for various amounts of reinforcing agent. Figure 1 indicates that the 32% group achieves a relatively constant rate within a relatively smaller number of reinforcements than do the other groups. The initial slopes of the acquisition curves increase with concentration. In terms of *time* to reach the final rate, there is a clear effect of concentration: stable rates are always reached with the higher two concentrations within minutes, and may not be reached within hours with 4% solutions. Hull's hypothesis is not conclusively disproved by the present evidence, but it is opened to serious examination, especially for very small amounts of reinforcing agent.

It is important to note that the amounts of food used here are far smaller than those used in other studies. One reinforcement of 4% sucrose in these experiments contains about 1/5000 gm. sucrose, while Zeaman's (**23**) minimum was 1/20 gm. and Crespi's (**1**) was 1/50 gm. of solid food. The amounts used here are also far smaller than ordinarily used in bar-pressing experiments. Skinner (**19**) used 1/20 gm. food pellets, and typically found an almost complete transition from the unconditioned to the conditioned rate of responding as the result of a single reinforcement. Gradual conditioning curves similar to those of the present 16% and 32% groups have been reported by Estes (**2**) in experiments with the present apparatus, but employing water reinforcement and thirst motivation. The present results and Estes' suggest that Skinner's conditioning curves are not necessarily prototypic of operant conditioning, but whether records like Skinner's can be produced by varying magnitude of reinforcement alone remains an open experimental question.

Resistance to extinction.—A relation between amount of reinforcement and resistance to extinction of bar-pressing has already been reported by Fitts (**4**), using 10 gr. and .2 gr. pellets. Reynolds (**14**) found no significant differences in resistance to extinction of bar-pressing among one 60 mgm., two 60 mgm., and one 160 mgm. pellets. The present results cast doubt on the generality of Reynolds' conclusions and on the "R-hypothesis" he proposes to explain the inappearance of an effect of amount of reinforcement in his study. It is suggested that all the amounts used by Reynolds were too close to the asymptote of the amount function to reveal significant differences in behavior with the *N*'s used.

Final rate of responding under continuous reinforcement.—In this experiment, resistance to extinction cannot be predicted from rate of responding under continuous reinforcement prior to extinction, since resistance to extinction is proportional to concentration over the entire range from 4% to 32% sucrose, and the "reflex reserve" developed with 32% is not indicated by the momentary rate of performance at a late stage of training. The most obvious hypothesis to account for the nonmonotonic form of the curves in Fig. 2 is more rapid satiation with 32% sucrose. Several facts make this hypothesis very dubious. In Fig. 1, the curve for 32% rises rapidly to a level which is below that later attained by the 16% and 8% curves, and it remains at this level with at least as much stability as is shown by the other curves. The individual 32% records do not suggest a satiation decrement, nor would a significant decrement be expected from the total amount of sucrose in 250 reinforcements of 32% solution, about .4 gm. Young (**22**) has found that a rat will ingest about 50 ml. of 32% sucrose in 24 hr., given no other food on the day of testing, which in his study follows a day of cafeteria feeding. What must be accounted for is that rate of responding on 32% never reaches the level obtained with 16%; if satiation is the responsible factor, its effects must be exerted before 1 ml. of liquid has been ingested.

Another explanation is suggested by Young's finding that ad libitum intake of sucrose solutions is a nonmonotonic function of concentration. He finds, however, that the maximum volume ingestion is at about 8.5%, whereas here the

maximum rate of bar-pressing must be at a value somewhere above 8%. Even without this disparity, however, appeal to such a hypothesis will not account for the greater resistance to extinction of the 32% group. In reviewing the present findings, Young[8] has suggested that greater rates of adaptation of the taste receptors at higher concentrations might be involved, leading eventually to a lowered sensory effect and reduced performance. This would imply that resistance to extinction is primarily determined by the earlier rather than the later reinforcements. This possibility is not inconsistent with the present data.

As a final suggestion, it may be that there is a prolongation of drinking behavior at the higher concentrations, contrary to the intended control over this factor. It is possible that at 32% the consummatory response affords sufficient competition to bar-pressing to depress its rate of emission. No actual measurements of the time of drinking were made, and this hypothesis cannot be directly evaluated. However, indirect evidence on this point is supplied by the findings with regard to periodic reinforcement, under which condition the consummatory response might be in competition with bar-pressing during only a small fraction of the interval between reinforcements. The PR determinations were, in fact, included in the study partly as a test of this hypothesis, and the results are consistent with this interpretation of the continuous reinforcement relationship. Decisive evidence on this problem is not available, however, and it cannot be resolved at this time.

Performance under PR.—The present data on PR, taken in relation to the findings for resistance to extinction, furnish the clearest evidence on the role of concentration of reinforcing agent. Methodologically considered, these relationships suggest that in studies of this type where an effect upon resistance to extinction is sought, the PR procedure provides virtually equivalent information with an economy of experimental effort.

The relationship between PR rate and concentration is a highly stable and reproducible one. Animals originally conditioned and given prolonged experience with various single concentrations behave very much alike when tested under PR on a number of concentrations. There is revealed no effect comparable to the "elation" or "depression" phenomena reported by Crespi (1) and Zeaman (23) occurring as the result of increases and decreases in amount of reinforcement. It is possible that these effects exist in this study in small measure but that the analysis was too gross to reveal them. If, as these writers suggest, these phenomena are emotional in nature, it is reasonable to expect that the effects should disappear through adaptation over the course of the numerous shifts in concentration in the second PR determination.

Theoretical considerations. — The methods and results of this study invite a reconceptualization of the reinforcing agent in such a manner that it can be explicitly treated as a *stimulus* and its properties and functions so described. When, following current drive-reduction notions, a piece of food is thought of primarily as a nutrient agent, the fact that reinforcements are stimuli is likely to be obscured or entirely overlooked. If, on the contrary, the stimulational function of the reinforcement is taken seriously, such a fact as the semilogarithmic relation between sucrose concentration and PR rate becomes strongly suggestive of commonly found relations of the same form between stimulus intensity and receptor activity or reflex magnitude. By setting aside the drive-reduction habit of thought, and by using certain obvious extensions of methods developed for sensory and reflexological research, direct investigation of the important properties of reinforcing stimuli may be permitted.

As a move in this direction, we have suggested an extension of the notion of the threshold to cover the case of reinforcement. The reinforcement threshold for sucrose estimated by extrapolation from the present data may not be accurate and may not coincide with the threshold for acquisition, since it is based on data for performance. But in general the utility of the threshold notion as an analytic tool is great, and its place in the scheme we are outlining can be made quite determinate: the events essential to the strengthening of instrumental behavior must be considered to be those which are initiated when the reinforcement threshold is reached.

[8] Young, P. T. Personal communication.

Hypotheses about the nature of these events cannot be confirmed until thresholds are precisely measured and are compared with independent measurements on the supposed underlying processes. Among a priori hypotheses, there is one which is readily testable by virtue of its simplicity: that the reinforcement threshold coincides numerically with the receptive threshold of particular end-organs and that it is invariant for a wide variety of conditions, including changes in drive. This statement amounts to a quantitative interpretation of Troland's beneceptor theory (**20**), which has already received some indirect support (**18**). Other more complex hypotheses regarding reinforcement are also susceptible to interpretation in terms of the reinforcement threshold and will be so treated in a later paper.

Summary and Conclusions

Four concentrations of sucrose, 4%, 8%, 16%, and 32%, were used as reinforcing agent with four groups of rats ($N = 80$) in a study of bar-pressing behavior. Each group received a single concentration during magazine training and conditioning under continuous reinforcement. Following extinction and reconditioning, performance was observed under periodic reinforcement for five days. Then, 20 *S*s from the various groups were tested under periodic reinforcement an additional 12 times with each of the four concentrations previously used.

1. The time required to condition and to execute 500 responses decreases as concentration increases.

2. The averaged acquisition curves indicate a positive relation between concentration and the rate of approach to the asymptotic rate of responding under continuous reinforcement.

3. The relationship between concentration and rate of responding under continuous reinforcement at various stages beyond 100 reinforcements is nonmonotonic, increasing to 16% and then decreasing.

4. Resistance to extinction in terms of rate of responding in the initial 15 min. of extinction is an increasing monotonic function of the concentration used in conditioning. For the first 5 min., the relationship is approximately logarithmic.

5. Rate of responding under periodic reinforcement is an approximately logarithmic function of concentration, as determined both by comparison of independent groups and by using each *S* as its own control.

6. The concentration used in conditioning appears to have no effect upon the rate-concentration function for periodic reinforcement.

7. Extrapolation of the rate-concentration curves suggests a reinforcement threshold in the region of the sucrose taste threshold as determined by preference tests. Some implications of this hypothesis are discussed.

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THE RELATION BETWEEN CONDITIONED STIMULUS INTENSITY AND RESPONSE STRENGTH

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A positive relation between intensity of the conditioned stimulus and response strength has been found in a number of studies. Much of the evidence for this relationship has been reviewed by Hilgard and Marquis (**7,** p. 141), and by Hull (**10**) who designated this relationship stimulus intensity dynamism. Two recent experiments with human *Ss* may be interpreted to support the existence of this relationship in the eye blink conditioned to a visual stimulus (**3**), and in the galvanic skin reflex conditioned to an auditory stimulus (**4**). Most recently dynamism has been found in an avoidance response to a light in white rats (**11, 12**).

Stimulus intensity dynamism has been obtained rather consistently (**3, 4, 7, 10, 11, 12**) following differential conditioning (such as classical conditioning) in which the positive stimulus is CS-plus-situation and the negative stimulus is situation-minus-CS. That differential conditioning is necessarily involved in classical conditioning and other procedures in which a response becomes attached to the onset of a stimulus has been pointed out by Skinner (**17**) and Mowrer and Lamoreaux (**14**). Furthermore, actual extinction of a generalized response to situation-minus-CS is evidenced by the early occurrence and later disappearance of what Pavlov (**15**) called a conditioned response to the environment and by the "spontaneous" jumping observed by Mowrer and Lamoreaux (**14**).

On the other hand, when no differential conditioning had occurred, some *Es* have found that an increase in visual (**6, 17,** p. 225) or auditory stimulation (**6,** p. 299) may depress the strength (rate) of a bar-pressing response. Thus, it is possible that dynamism is an artifact of a differential training procedure.

The following analysis of just what is involved in differential conditioning will disclose *specific* theoretical reasons for expecting dynamism to result from differential conditioning where the negative stimulus is situation-minus-CS. The results of such differential training are represented graphically in Fig. 1. In this figure a CS of medium intensity is at point *M* on the horizontal axis. Stimuli *L* and *G* of less and of greater intensity are equally distant from the CS (on a psychophysical scale). The solid line is the gradient of generalization of the effects of reinforced presentations of a CS of medium intensity. As indicated in the figure, there is considerable generalization of the effects of conditioning to a stimulus of zero intensity or situation-minus-CS. The dashed line represents generalization of extinction effects from the negative stimulus of "zero intensity."

On the assumption that these extinction effects may be subtracted from the effects of positive training to give response strength, the difference between the height of the two gradients represents response strength for the

[1] The writer expresses his indebtedness to Mr. Guido Borasio for wiring the apparatus and running five *Ss*, and to Dr. Martin Baron for several helpful suggestions in the preparation of the manuscript, but assumes full responsibility for the experiment and its interpretation.

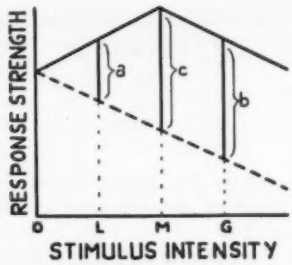

FIG. 1. Schematic representation of generalization along the intensity dimension following reinforcement of responses to a CS of medium intensity (*M*) and nonreinforcement of responses to a stimulus of zero intensity (0)

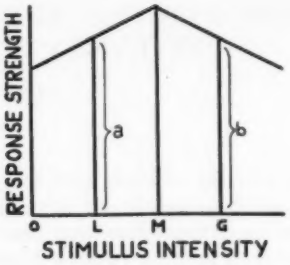

FIG. 2. Schematic representation of generalization along the intensity dimension following training which involves only reinforcement of the response to a CS of medium intensity (*M*)

appropriate stimulus.[2] Thus, the length of line *a* represents the response strength for a stimulus (*L*) of less intensity than the training stimulus. The distance *b* represents the strength of the response tendency to a stimulus (*G*) of greater intensity than the training stimulus (*M*). Thus, although generalization of the effects of *positive* training are the same, there is greater response strength to Stimulus *G* than to Stimulus *L*. This difference is the result of greater generalization of extinction effects to *L* than to *G*.

It should be noted that this derivation is dependent only on two very general assumptions about the nature of generalization gradients: (*a*) that the gradient is symmetrical, and (*b*) that the greater the difference between training and test stimuli the greater the generalization decrement.

During those types of instrumental training, such as simple operant conditioning, which do not involve differential training, there is no extinction of the response in question to a stimulus of zero intensity. Thus, such training may be assumed to produce results such as those represented in Fig. 2. Of particular importance is the specific implication that in this case the same response strength will be found to two stimuli one more and the other less intense than the CS whenever these two stimuli are the same number of j.n.d.'s from the CS (e.g., $a = b$ in Fig. 2).

The present study is designed to determine if generalization of a bar-pressing response along the intensity dimension is symmetrical following two kinds of training: (*a*) simple positive training, and (*b*) differential conditioning where the negative stimulus is situation-minus-CS. Thus, it is also a test of the hypothesis that stimulus intensity dynamism may be the result of differential conditioning. Tests of response strength to stimuli of greater and less intensity than the CS were made following two training procedures which were quite similar except that one involved differential training and the other did not.[3] Some rats (Group P) were given extensive

[2] This formulation is in general outline, but not in specific detail, an application of Spence's theory of discrimination learning (16, 17) to stimulus intensity dynamism.

[3] Differential training of approach or orienting responses was probably involved for both groups but here the negative stimulus was absence of the bar, which is not relevant to stimulus intensity as defined in this study. Differential conditioning refers here only to training which was differential with respect to the stimulus (light) the intensity of which was altered on test trials.

training under partial reinforcement conditions in the presence of a light of medium intensity. Others (Group D) were given differential training in which the medium intensity light was present on reinforced trials and absent on nonreinforced trials. Both groups were subsequently tested under three conditions: (*a*) with the same light as that used during training (Cond. M); (*b*) with a light of greater intensity (Cond. G); and (*c*) with a less intense light (Cond. L). According to the differential conditioning hypothesis, Group D should make shorter latency responses under Cond. G than under Cond. L. On the other hand, Group P should not show any difference in response latency under test Cond. L and G.

Method

Apparatus.—A modified Skinner box, the interior of which was a 12-in. cube, was used. Its walls were painted flat white, except for an 8 by 8-in. flashed glass stimulus window in the center of the roof and a small observation window in the front of the box.

The bar slot was situated on the back of the box midway between the two sides. When withdrawn the bar could be mechanically thrust into the apparatus. Bar presentation was accompanied by a loud thump as the frame holding the bar struck the outside of the box. Upon depression of the bar, the food release mechanism was activated making a distinct click.

A metal food tray was fastened on the back left-hand corner of the floor. A glass tube through which the food pellets were presented projected through a hole in the back of the apparatus above the food tray. A small glass dish containing water was placed in the back right-hand corner.

Projecting directly up from the top of the apparatus was a 42 in. high light control box of 8 by 8-in. horizontal cross section which contained flashed glass plates, removable light intensity control screens, and a 750-w. bulb. The lower end of this box was the piece of flashed glass which also formed a part of the roof of the Skinner box. Four inches above this there was another horizontal pane of flashed glass which filled the entire cross section of the box. Two inches above this point and 6 in. above the roof of the Skinner box were narrow slits extending horizontally across two adjacent sides of the box into which the light-intensity control screens could be pushed. These screens were 8 by 9-in. sheets of galvanized iron with a ¼-in. slit running the full length of the screen midway between the two sides. There was a third piece of flashed glass 2 in. above the slits for the light control screens. A 750-w. bulb was 19 in. from the light control screen and 25 in. from the flashed glass pane in the roof of the Skinner box.

When the bulb was lighted and neither light control screen was used, the intensity of light on the floor of the Skinner box was approximately 20 ft.-candles. When one light control screen was in place, light could pass through only 1/32 of the cross section and thus the light was cut down to 1/32 of the intensity present with no screen. When the second screen was in place (with the slit at right angles to the first) the intensity of light was cut down to 1/32 of the medium intensity. Thus, three intensities of light, one of which was midway between the other two on a logarithmic scale, could be provided.

The light circuit was interrupted regularly, each off-on cycle lasting 1.1 sec., the light and dark periods each being .55 sec.

The experimental room was dimly lighted by a 6-w. bulb placed on top of the Skinner box. Some light from it entered the Skinner box by the bar slot, the glass food delivery tube, and the observation window on the front of the box. Whenever the bulb in the light control box was on, the Skinner box was considerably lighter than the room outside, but whenever this light was off, the Skinner box was not completely dark.

The experimental room was relatively free from extraneous noises and these were almost completely masked by the operation of an electric fan.

Subjects.—The *S*s were 20 experimentally naive female albino rats from the Kent State University colony. Five highly emotional *S*s were discarded during preliminary training while the procedure was the same for all *S*s. Two were discarded during partial reinforcement training when they ceased depressing the bar. One *S* was discarded due to failure of the apparatus. The 12 *S*s for which data are reported were approximately 4–5 months old when training was initiated.

Experimental procedure.—The *S*s were first reduced to approximately 80% of their normal body weight by small daily feedings. About ten days were required to reduce *S*s to this weight (132–178 gm.) at which they were kept throughout the experiment by daily feedings immediately after the experimental period.

The procedure during preliminary training, the training series, and test days is summarized in Table 1. Conditions L, M, and G refer,

respectively, to the intermittent light of least, medium, and greatest intensity. No light means the intermittent light was off, but some light entered the box from the 6-w. bulb on the top of the Skinner box. All reinforced responses were followed by a click and a .14-gm. food pellet. Nonreinforced responses were followed by click alone. As can be seen from the table, the preliminary training, which was the same for both groups, served to establish the bar-pressing response under Cond. M for all *S*s. Throughout the entire experiment the interval between a response and the next bar presentation was 30 sec.

The training series was initiated 23–24 hr. after the completion of preliminary training. The partial reinforcement *S*s (Group P) received 20 bar presentations under Cond. M each day for the 20 training days. Six responses were reinforced and 14 were nonreinforced. A prearranged schedule was set up so that, while the order of reinforced and nonreinforced trials was different each day, there were two reinforcements on Trials 1–5 and 11–15, and one reinforcement on Trials 6–10 and 16–20. The schedule was identical for all *S*s. If *S* did not respond within 30 sec. (as happened on only a very few trials) the bar was withdrawn. If no response occurred on a trial which had been designated as a reinforced trial the next trial was reinforced. In this way every *S* received 6 reinforcements in a total of 20 bar presentations on each of 20 days.

The differential conditioning *S*s (Group D) received the same schedule of reinforcement for the same number of days as Group P. However, Group D *S*s received their nonreinforced trials under the no-light condition. Whenever the reinforcement schedule called for a change in light conditions this occurred 15 sec. after one response (or bar withdrawal) and 15 sec. before the next bar presentation. The light condition on nonreinforced trials is the only thing which differentiated between the two groups.

On the first test day Trials 1, 3, and 5 were reinforced; Trials 2 and 4 were like the nonreinforced training trials for that *S*'s group. Following these five trials *S* was returned to its living cage for 5 min. and then replaced in the box under either Cond. L, M, or G. Five nonreinforced test trials were given starting 30 sec. after *S*'s introduction to the box. Following these trials *S* was again returned to his living cage for 5 min. and subsequently given five test trials on another light condition. After another 5 min. in the living cage *S* was given five test trials on the third light condition. Each of the six possible orders of the three light conditions was used for one of the *S*s in each group.

On the final day all *S*s were given five trials on each light condition. The test conditions were again separated by 5 min. in the living cage and were given in an order the reverse of that used on the preceding day. Further tests were

TABLE 1
EXPERIMENTAL PROCEDURE

Day	Group P	Group D
	Preliminary Training	
1	3 pellets in food tray 5 click-foods, Cond. M	
2–3	10 click-foods, Cond. M	
4	10 reinforced bar-depressions, Cond. M	
5	20 reinforced bar-depressions or to criterion of 5 successive responses of less than 5-sec. latency, Cond. M	Same as Group P
6–7	Same as Day 5, if needed to reach criterion	
	Training Days	
1–20	6 reinforced responses, 14 nonreinforced bar presentations, all under light Cond. M	6 reinforced responses, light Cond. M 14 nonreinforced bar presentations with no light
	Test Days	
1	3 reinforced and 2 nonreinforced presentations, light Cond. M 5 nonreinforced trials on each of Cond. L, M, and G	3 reinforced trials, light Cond. M 2 nonreinforced trials, no light 5 nonreinforced trials on each of Cond. L, M, and G
2	5 nonreinforced trials on each of Cond. L, M, and G	5 nonreinforced trials on each of Cond. L, M, and G

run on some of the *Ss* which indicated that Cond. L was clearly discriminable from "no light."

Results

The *Ss* in Group D were responding differentially to the positive and negative stimuli (light and dark, respectively) on the last day of training. Only 3 to 11 of the 14 presentations of the negative stimulus to each *S* were responded to within the allotted 30-sec. period. During the same period the longest latency of a response to the positive stimulus for individual *Ss* ranged from .5 sec. to 13.4 sec.; the median latency ranged from .3 sec. to 2.0 sec.; and the shortest median latency of any *S*'s response to the negative stimulus was 5.6 sec. On this last day of training the latencies of responses to positive and negative stimuli for each individual *S* differed significantly at the 5% level or better (single-tail hypothesis) as measured by the Mann-Whitney *U* test (**13**).

The *Ss* in Group P were making about the same response latencies at the end of training as were the Group D *Ss* in response to the positive stimulus at the end of their training. On the last training day median latencies for individual *Ss* in Group P ranged from .35 sec. to 2.15 sec.

The methods of presenting the results of test trials are somewhat limited by the type of measures obtained. First, means could not be used since on some trials for Group D no response occurred within the 30 sec. allowed. This was especially true of Cond. L where four *Ss* did not make a response on at least half of the test trials. Second, since response latencies were markedly skewed to the right, it seemed advisable to transform the measures. Two transformations were used: (*a*) reciprocal of latency (in seconds), and (*b*) 2−log latency (in seconds). Both these derived scales are similar in that greater response strength is indicated by a larger value.

The data presented in Table 2 were obtained by: (*a*) transforming all latencies to the appropriate derived values, (*b*) obtaining the median for each *S* on each test condition, and (*c*) determining the median of the medians for the six *Ss* in each group under each test condition.

As can be seen from Table 2, *Ss* in Group P evidenced about the same response tendency under each of the test conditions although the medians suggest slightly greater response tendency of the generalized responses (Cond. L and G) than of the conditioned response. However, these differences are not significant. No more than 4 of the 6 *Ss* showed a difference in the same direction in any comparison between the medians for the different test conditions.

On the other hand, *Ss* in Group D showed greater response strength with more intense stimuli for both measures used. Under Cond. L the median could not be calculated because of the frequency of failures to respond within 30 sec. Response strength is intermediate under Cond. M and strongest under Cond. G. That these differences are reliable is indicated by the consistency of the results for individual *Ss*. Response strength measured by the median of either reciprocal of

TABLE 2

Median of the Medians in Reciprocal of [Latency and 2−Log Latency in Seconds

Test Condition	Reciprocal of Latency		2−Log Latency	
	Group P*	Group D*	Group P*	Group D*
L	1.75	<.03	2.34	<.52
M	1.50	.39	2.16	1.43
G	1.71	.78	2.33	1.84

* $N = 6$.

latency or 2−log latency was greater under Cond. G than Cond. L for all six *S*s. This result would occur only 1 time in 64 due to chance alone. Response strength was greater under Cond. G than M and under M than L for 5 of the 6 *S*s.

The results for both groups are in complete agreement with deductions from the differential conditioning interpretation of stimulus intensity dynamism. As predicted, *S*s given differential training evidenced significantly greater response strength (shorter latency) under Cond. G than under Cond. L. On the other hand, the difference between the medians of the median latencies on Cond. L and G for *S*s given partial reinforcement was remarkably small and could be attributed to chance.

The differential training *S*s also made longer latency responses under Cond. L than Cond. M and under Cond. M than G. Although these differences are not statistically significant, the trend is clear-cut.

On the assumption that the true differences are in this direction, a graphic representation for the differential training group similar to Fig. 1 must be so constructed that $b > c$ and $c > a$. It will be recalled that $b = c$ in Fig. 1. If positive and negative gradients are the same in shape, such a figure necessarily involves either (*a*) a steeper generalization gradient of extinction effects than of the results of positive training, or (*b*) generalization gradients which are convex (upward) through at least part of the range.

Discussion

The differential conditioning hypothesis will not explain those instances of stimulus intensity dynamism which were obtained following nondifferential training. However, the present study and others (**6, 17**) indicate that there may not be any tendency for dynamism to occur following nondifferential training. Thus, it seems likely that special conditions are responsible for the occurrence of dynamism when it is obtained following nondifferential training.

The occurrence of dynamism in an approach response which has been reported by Brown (**2**) and by Grice and Saltz (**5**) may be explained by the increase in intensity of the stimulus with greater proximity of *S* to the stimulus. That is, as *S* approaches a light (**2**) or a white circle (**5**), the stimulus may become perceptually "more intense" (brighter or larger). Thus, the interaction of the goal gradient and stimulus generalization may produce a stronger tendency to approach relatively intense stimuli which have been followed by immediate reinforcement. That some such factor is operating is suggested by Zaynor's study (**20**) in which no evidence of dynamism in an approach response was obtained on a slight modification of the apparatus used by Raben (**16**) where the intensity (white as more intense than black) was not affected by nearness to the goal. In this apparatus the color of the runway was the same as that of the (black or white) goal box and thus nearness to the goal box would presumably have no effect on "stimulus intensity."

The results of Spence's experiment cited by Hull (**9, 10**) are less easily explained without assuming dynamism as a postulate. In this study rats made fewer errors in learning a black-white discrimination when white was positive and black negative than when black was positive and white negative. Hull (**10**) interpreted this as evidence for dynamism, but the result could also be assumed to result from an original preference for white.

In the Hays study cited by Hull (**10**) two groups of rats were trained to jump to a single stimulus card in a jumping stand. At the limit of learning the group which was trained to a white stimulus card had a shorter response latency than the group trained to a black card. Since this experiment is not reported in detail, an entirely satisfactory analysis of the factors involved is impossible. However, if the black and white stimuli were set in a black background, the white stimulus card would differ more from the background than would the black card. Presumably, the response of orienting towards or "looking at" black background would be extinguished and the effects of this extinction would generalize more to a black stimulus than to a white one. Thus differential conditioning of orienting responses may be involved. A study by Bragiel (**1**) supports this interpretation. Using a procedure similar to that of Hays, he found

that when the background was black, jumping speed was greater to a white card than to a black one, but that when the background was white, jumping speed was greater to a black card. It thus appears that stimulus intensity must be defined in terms of contrast rather than in terms of absolute physical intensity. Bragiel's results also suggest that differential training may frequently be involved in situations where a cursory glance at the procedure would not disclose it.

While the issue is far from settled, it seems most reasonable to assume that there is no need to postulate stimulus intensity dynamism as a basic assumption since all cases of this phenomenon may be derived from other postulates of behavior theory (8).

Summary

In a test of the hypothesis that the positive relation frequently obtained in other experiments between intensity of the CS and response strength may be the result of differential training necessarily involved in Pavlovian conditioning or any other procedure where the CS is the onset of stimulation, two groups of six white rats each were given extensive training on a bar-pressing response. One was trained by partial reinforcement while a light of medium intensity was present. The other was given differential reinforcement, the light accompanying reinforced responses and darkness accompanying nonreinforced responses. All *S*s were tested in the presence of the light of less, medium, and greater intensity. The partial reinforcement *S*s did not respond differentially under the three test conditions. The differential conditioning *S*s made the longest latency responses in the light of least intensity and the shortest latency responses in the light of greatest intensity. These results are in complete agreement with deductions from the differential conditioning interpretation of the relation between stimulus intensity and response strength.

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THE INFLUENCE OF PRACTICE ON THE STRENGTH OF SECONDARY APPROACH DRIVES[1]

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This paper reports a preliminary attempt to identify and demonstrate the effects of "wanting-practice" as a variable influencing the reward value of a secondary reinforcer.

Hull's statement (**2, 3**) of the secondary reinforcement principle, and further discussion and experimentation on the problem (**6**) have tended to separate it from the problem of secondary drive. This has fostered a neglect of the wanting-practice variable, for the latter is defined in terms of the time that the secondary drive spends in an aroused condition. In favor of the variable is the prima facie reasonableness of the suggestion that mere "practice at wanting" should strengthen the want being practiced without any increment in primary reinforcement to accompany the increase in time. The hypothesis is superficially Guthrian, asserting that by mere doing, the doing becomes more likely. The *doing* in the present case is *wanting*. Actually the derivation is from a more complex theory (**9**) which we will mention again later.

In order to render the hypothesis explicit, it is necessary to define briefly the concept of secondary drive used here. Hull's primary drive, D, may be used as the model. D is a state variable presumed to be aroused by a primary instigating stimulus or operation, S^I, such as deprivation or shock, and presumed to be terminated by a primary reinforcing stimulus S^R. Secondary drive is a state variable d like Hull's D, the only difference being that d is learned. The secondary drive d is aroused by a secondary instigating stimulus S^i and terminated by a secondary reinforcing stimulus S^r. We may define wanting-practice then as the time that d spends in an aroused condition, that is, the sum of the time intervals from S^i to S^r in the absence of interfering conditions. Our theorem for test is that the reward value of S^r will be a function of wanting-practice. That is, the reward value of a stimulus will be a direct function of the amount of time S has spent wanting it.

Since wanting-practice is defined in terms of the time interval between S^i and S^r, and since we understand clearly the concept of the secondary reinforcer S^r, we have only to formulate an operational definition of S^i to render our theorem specific and testable. The hypothesis put forth in this regard is the following: after S has overlearned a stimulus-response sequence including an S^r and an S^R of the form S^N-R^1-S^r-R^2-S^R, the proprioceptive feedback from R^1 will constitute the secondary instigator S^i for the d involved. Later, other stimuli which have regularly accompanied the aroused condition of d will also become secondary instigators.

While S is overlearning the S^N-R^1-S^r-R^2-S^R sequence, wanting-practice will be negligible, for S performs R^1, and S^r is produced immediately. S^r becomes, during this training, a sec-

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ondary reinforcer in the Hullian sense, by virtue of its place in the sequence leading to S^R. If S should "want" S^r at this point, he would "want it as a means to S^R" but it would not have any "intrinsic value." After the overlearning, however, we may *delay* S^r with reference to its usual place in the overlearning sequence (so that R^1 is not anymore immediately followed by S^r). During these intervals of delay, S will "spend time wanting S^r as a means." But our theorem is that this time spent wanting it as a means will tend to strengthen d as a structure within the organism, and thus, the intrinsic reward value of the secondary reinforcing stimulus S^r will grow.

Because of the assertion that the *strength* of d (operationally defined by the reward value of S^r) increases as a function of *time* of arousal alone (without any increase of primary reinforcement), our hypothesis is more compatible with an *S-R* contiguity theory than with a strict *S-R* reinforcement position. The specific reformulation of Hull's theory which justifies this theorem appears elsewhere (**9**).

It should be noted that our hypothesis constitutes a denial that the law of the temporal gradient of reinforcement (**2**, p. 158) will apply, under the special circumstances outlined above, to the case where a secondary reinforcer is the reinforcing stimulus in question. That is, the delay of secondary reinforcement *after overlearning* (with respect to the overlearning sequence) will tend to increase the reward value of S^r, and thus the strength and likelihood of responses leading to S^r, including the response after which the delay occurs. Thus, in this circumstance, the delay of secondary reinforcement should strengthen rather than weaken the response which it follows.

Experiment I

The first experiment investigated the effect of wanting-practice on the reward value of a secondary reinforcer. Owing to loss of *S*s, only the gross directional effects of the variable could be studied.

The *S*s were habituated to a sequence which involved working a standard amount for tokens, S^r, and using these tokens to procure ulterior reward, S^R. After overlearning this sequence, *S*s were divided into four groups. Group A *S*s were switched from the learning sequence to one in which they worked approximately four times as long for S^r as they had in the overlearning sequence (thus there was a long interval of wanting-practice between expected token presentation and actual presentation). Group B was switched from the learning sequence to one in which they worked approximately 2.5 times the original amount for S^r. Group C, the control, worked the original amount. Group D worked one-third of the original amount. Token reward value was measured before and after these delay operations. The directional prediction was this: the groups that experienced the delay of S^r (Groups A and B) would show a significant increase in the reward value of S^r as compared to the groups that did not experience the delay (C and D).

Procedure

Subjects.—Fourteen 4-5 year old children, both girls and boys, from classes of the Harvard Nursery School, were used. Twenty-two *S*s received preliminary training but eight were absent on either the first or second measurement days, and thus they could not be used.

Apparatus.—The basic apparatus in both experiments was the crank-chip machine described by Lambert (**4**). This is a device which allows *S* to turn a crank to obtain a poker chip token. The number of turns of the crank per chip can be varied by *E*. Also, *E* can stop the machine completely when *S* has obtained his allotted number of chips.

A counteracting pressure recorder, designed by the author and Mr. Henry Gerbrands, is attached to the chip machine to record automatically the amount of effort expended by *S* in cranking. The recorder functions by interposing automatically the amount of resistance required to restrict *S*s to a slow constant cranking speed (approximately 1 rps), and by measuring continuously the resistance required. Speed is controlled by a Watt-type governor. When the governor passes the critical speed, it closes a switch which allows air pressure to build up in an air brake which slows the cranking. Pressure

continues to build up until *S* falls below the critical speed at which point pressure begins to fall and continues to fall until *S* again exceeds the critical speed. The amount of pressure in the air brake is measured by a pressure gage and recorded continuously on a wax-paper kymograph. Although not in one-to-one correspondence at all times, the average counteracting pressure is a direct function of the amount of effort expended by *S*.

The scores obtained are average curve heights during an interval of cranking. Average heights were obtained by tracing the perimeter of the curves with a planimeter to obtain areas and dividing by the base line to obtain scores. During each measurement *S* cranked continuously until he had obtained eight chips at three turns of the crank per chip. The counteracting pressure is taken to be a measure of the reward value of S^r when other factors are held constant. Other variables such as motor skill and physical capacity and the value of the ulterior reward undoubtedly affect the measure. But, since only *gains* in effort made during treatment are used, skill and capacity are canceled out; and expectation of ulterior reward was constant for all *S*s and for first and second measures.

It should be noted that there were slight changes in the characteristics of the measuring system from day to day. The temperature and normal wear and tear on the apparatus led to small variations at three points: (*a*) the speed setting of the governor, (*b*) the original tension of the brake band on the brake drum, and (*c*) the output of the air pressure generator. For these reasons, *S*s in all groups had to be measured on the same days in order for the measures to be comparable.

Further apparatus included chip-bags in which *S*s saved their earned chips, and a play-store at which *S*s bought penny toys at four chips apiece.

Habituation.—During habituation *S*s cranked out a total of approximately 160 chips, at the rate of 3 turns of the crank each, and at the rate of 8 chips a day, for 5 days a week, for 4 weeks. Chips were spent at a play-store in exchange for penny trinkets on Wednesdays and Fridays. A goal gradient appeared as learning progressed; *S*s cranked harder on Wednesdays and Fridays than on other days. Therefore, first and second measures had to be taken on the same days of different weeks to be comparable.

Delay treatment.—For the delay treatment, *S*s were divided into four groups; the aim was to get five *S*s in each group. Groups were roughly matched for effort expenditure on the pretest, and for sex. After absenteeism had decimated the groups, four *S*s were in Group A, two *S*s in Group B, five in Group C, and three in D.

TABLE 1

GAINS IN EFFORT POINTS FROM THE FIRST TO THE SECOND TEST: EXP. I

Group	Individual Subjects					Mean
	1	2	3	4	5	
A	−3.5	4.5	5.7	18.9		6.4
B	.4	20.4				10.4
C	−3.3	−17.3	− 7.8	2.2	−11.7	− 7.6
D	−1.7	−15.0	−17.1			−11.3

All groups received three days of delay treatment, with the difference that Group A received chips at a varied schedule of delays averaging about 12 turns of the crank per chip (but varying from 3 to 36 turns), Group B received chips at a varied schedule of delays averaging about 7.5 turns (but varying from 3 to 18 turns), Group C received chips at 3 turns as during habituation, and Group D received chips at 1 turn. All *S*s still cranked out eight chips a day and spent them at the play-store on store-days.

Tests.—On the Tuesday before the start of the delay treatment on a Thursday, and on the Tuesday after the end of delay treatment on a Monday, the counteracting pressure recorder was used to measure for each *S* the effort he expended while cranking consecutively for eight chips at three turns of the crank per chip. Gains from the first to the second tests are taken as measures of the increases in the reward value of S^r produced by the delay treatment.

Results

Table 1 presents the effort gains made by all *S*s from the first test to the second test.[2] It is immediately obvious that the general directional hypothesis is validated; Groups A and B, which experienced the delay, are higher than Groups C and D, which did not. A *t* test of the difference between the group means (**11,** p. 82) shows the difference to be significant beyond the .01 level. Also, using a directional test, the difference between Groups A and B on the one hand and Group C

[2] Owing to the day-to-day variations in the measuring system, only the differences between the groups (not the absolute values of the gains) have meaning. Also, because there were only two *S*s in Group B, the 10.4 figure in that column is not dependable.

alone on the other is significant beyond the .01 level.

On the other hand, the difference between Groups C and D was expected to be zero or in the negative direction. It turns out to be negative, but the difference is not significant.

Experiment II

Because before and after measures of reward value can be taken on "store-days" when S^r has more instrumental value, and on "non-store-days" when S^r has less instrumental value, the second experiment was designed to find which set of gains is most influenced by the delay treatment. The question is whether the increments in reward value produced by delay treatment will show up best when instrumental value is high or when it is low. Wednesdays were "store-days"; Tuesdays were "non-store-days."

Procedure

Twelve *S*s of the previous experiment were given four weeks of refresher habituation. Then they were divided into two new groups to receive five days of delay treatment. The procedure duplicated that for Groups B and C of Exp. I. On the Tuesday and Wednesday before the start of delay treatment (which started on Monday) and on the Tuesday and Wednesday following delay treatment (which ended on Friday), the counteracting pressure recorder was used to measure effort expended by each *S* while he cranked consecutively eight chips at three turns of the crank per chip.

Results

Table 2 presents the effort gains by the two groups from Tuesday to Tuesday (low instrumental value) and from Wednesday to Wednesday (high instrumental value). The Group B T-T gains exceed those of the control by 11.0 points which is significant beyond the .05 level. The Group B W-W gains exceed those of the control by only 1.4 points, which is not significant. Because Group B is better than C on both T-T and W-W gains, the difference between the differences is not significant. The T-T results again sustain the basic theorem that delay treatment increases the reward value of S^r. If the difference between the differences should turn out to be real, this would suggest that the increase in reward value will show up best when the instrumental value of S^r is low (T-T), or else that the effect of delay treatment diminished with the passage of time.

Discussion

The results of these experiments show that if *S*s are habituated to a sequence including both an S^r and an S^R by long overtraining, and if then S^r is delayed by reference to its usual place in the habituation sequence, this delay of S^r will produce an increase in its reward value. These results testify to the induction and strengthening of d (the secondary drive directed at S^r) by habituation-and-delay operations.

There are some parallels between the present data and those found in studies of hoarding (**7**, **8**) and oral behavior of infants (**5**, **10**). The hoarding studies have shown that after an S^r, the pellet, has been made, by habituation, a regular means to hunger reduction, then starvation (which involves not only hunger but also

TABLE 2

Gains in Effort Points in Exp. II

Group B: 7.5 Turns			Group C: 3 Turns		
S	T-T Gain	W-W Gain	*S*	T-T Gain	W-W Gain
1	4.0	.2	8	−8.0	−16.2
2	5.5	−6.3	9	−.8	−15.7
3	19.8	2.7	10	7.5	−10.0
4	10.5	−18.1	11	−12.2	−8.0
5	3.0	−23.2	12	.8	5.7
6	16.4	−12.3			
7	−.4	5.2			
Mean	8.5	−7.4	Mean	−2.5	−8.8

delay of pellets) produces a marked increase in the reward value of pellets measured by the tendency to acquire pellets even when there is no hunger.

Similarly, the work of Levy (5) and Sears and Wise (10) on oral drive in infants shows (*a*) that after children have learned to suck as a means to food, deprivation vis-à-vis sucking increased the tendency to suck, but (*b*) if children never learn to suck as a means to food, being cup-fed from birth, then deprivation vis-à-vis sucking does not increase the sucking tendency.

Hull's theory of secondary reinforcement (2, 3) gives sparse interpretation of our results. The theory holds that stimuli acquire their S^r capacity by pairing with S^R's as a function of the time intervals between S^r and S^R. The longer this time interval, the less reinforcing capacity they acquire. Furthermore, the greater the reinforcing capacity of the S^R used, the greater the acquired capacity of S^r. The effectiveness of S^r's in strengthening responses is presumed to be a function of their acquired reinforcing capacity and the immediacy with which they follow responses which they are to reinforce. Thus, secondary reinforcement theory would suggest that our habituation training should produce and increase the secondary reinforcing capacity of the token rewards. However, there is nothing in Hull's formulation to suggest that our delay treatment should further strengthen this secondary reinforcing capacity. The fact, indicated by our results, that under special circumstances the delay of S^r produces an apparent strengthening of the antecedent response, rather than a weakening, is diametrically opposed to a prediction based on Hull's temporal gradient of reinforcement that such a delay should weaken rather than strengthen the response.

It should be pointed out that these results were not genuinely derived from the commonsense notion of "wanting-practice," nor merely from the criticism of Hull for neglecting to connect the problems of secondary reinforcement and secondary drive. Rather they were derived from a theoretical explanatory scheme, based on Hebb's (1) discussion of "cell-assemblies," and generated by the aim of getting the latent learning data (12) under the rubric of an objective theory such as Hull's. The theory (9) is much too detailed to set forth here.

Summary

In Exp. I, 14 children were habituated to a stimulus response sequence of the form S^N-R^1-S^r-R^2-S^R by a long overlearning. Then, during delay treatment, the sequence was repeated, except that, by reference to the habituation sequence, the R^1-S^r interval was (in Groups A, B, C, D) 4 times, 2.5 times, the same, and ½ what it had been during habituation. Measures before and after the delay treatment showed that the groups which experienced the delay in S^r (A and B) increased their valuation of S^r significantly as compared with control Group C ($p > .01$). Group D showed a slight and non-significant decline in valuation of S^r as compared with the control group.

In Exp. II, 12 *S*s of Exp. I were divided into two groups and treated like Groups B and C of Exp. I. Two measures were taken before delay treatment and two measures were taken afterwards. One (prior-post) pair was taken when S^r had small instrumental value, the other when S^r had high instrumental value. Group B showed significant value gains (as compared to control Group C) only when the instrumental value of S^r was low. However, the difference between the differences was not significant.

The results were interpreted as indicating that "wanting-practice" increases the reward value of S^r.

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THE RELATION OF IRRELEVANT-INCENTIVE LEARNING TO MOTIVATION AND REWARD DURING EXPLORATORY EXPERIENCES AND TRAINING[1]

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Recently Christie (1) has reported a series of experiments in which he investigated the influence of both early deprivation and early exploratory experiences on the behavior of rats in an Iowa type latent learning situation (4). His results differed from earlier reports (4, 8) which showed that irrelevant-incentive learning is absent when the drive dominant during the training period is rather strong. In all of Christie's experiments, in which the training period involved the *Ss* being hungry and a water bottle being in one end box and food in the other, the *majority* of the *Ss* went to the water side on the first test trial after having been made thirsty.

Christie's interpretation of his results on the first test trial was vitiated to some extent by the fact that in three of his four studies, the *Ss* on the second and third test trials, when motivated by hunger, which was the prevailing motivation during training, responded essentially in a chance manner. These results were also at odds with those of the Iowa studies (4, 8) since *Ss* in the Iowa investigations gave ample evidence during the test series of having learned the position of the commodity for which they had been motivated during the training series. The one exception was the performance of Christie's Group D whose early exploratory experience consisted of being placed on a table top while satiated and left there for 24 hr. At least 8 of the 9 *Ss* in this group responded appropriately on any test trial whether they were motivated for food or water, i.e., the irrelevant-incentive learning in this group did not occur at the expense of the relevant-incentive learning. It was deemed advisable, therefore, to investigate the experimental procedure underlying the results of Christie's Group D in the hope of isolating the relevant variables. The two studies contained in the present paper are attempts to do this.

The aim of the first experiment, in addition to duplicating the results of Christie's Group D, was to discover whether the early exploratory experience produced a general ability in the white rat to learn the position of irrelevant goal objects (either food or water) under relatively strong relevant drives. This was accomplished by giving two groups of *Ss* the same pre-experimental experience as received by Christie's Group D and having one group receive its experimental training trials under a hunger drive (as occurred in Christie's study) while the other was motivated by thirst.

The second experiment was designed to determine the role of motivation and reward during the exploratory

[1] This paper is a portion of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the Department of Psychology in the New York University Graduate School of Arts and Science. The author wishes to express his appreciation to Dr. Howard H. Kendler and to Dr. Richard Christie for their invaluable suggestions and criticisms.

[2] Now at the Human Resources Research Office, The George Washington University.

experiences. This was accomplished by limiting the exploratory experiences on the table top to 1 hr. and having one group highly motivated for both food and water with these commodities being present; a second group being satiated for both commodities but having them available during exploration; while a third group was also satiated but the food and water were not present on the table top during the exploratory period. All these groups received their training trials when motivated by hunger.

Experiment I

Procedure

Subjects.—The *S*s for this experiment were 22 male albino rats of the Wistar strain purchased from the Albino Farms, Red Bank, New Jersey.

Apparatus.—The T maze used in this study was of the same dimensions and design as the one described by Christie (1) and Kendler (3). It was painted flat gray throughout. As in Christie's maze, the food was found in a container in front of a wire mesh wall in one goal box, and the water was found in a bottle protruding through the wire mesh wall in the other goal box. The exploratory apparatus was identical in design to that used by Christie in his original study. The exploratory training consisted of exploration and living in a noncage environment (i.e., a table top). The table was painted flat black and was covered with sawdust. In the center of the table was a wire cage with food and water bottles mounted on it (perceptually similar to the water and food in the home cage and goal boxes of the T maze used later in the experiment). Connected to the table was an elevated path, 48 in. long and 2 in. wide, also painted flat back. A U-shaped section, with each of its separate parts being 12 in. in length, was added to the elevated path on one-half of the exploratory runs. During the exploratory trials, the exploratory table was moved about the room in a systematic manner. The position and direction of approach of the elevated alley were alternated, as was the position of the table with respect to electric light bulbs. Food and water were always found in the center of the table but the absolute distance between the start of the elevated alley and the reward was varied through the addition of the U-shaped segment on one-half of the exploratory trials.

Early experience.—Twenty-two rats, approximately 21 days old, were put on a diet of powdered dog chow and water for six days while in their home cages. The food and water were always present. Water was in the usual "upside-down" bottle with a glass stem attached; powdered food was in a trough-like, upside-down butter dish top. On the twenty-seventh day of life the exploratory periods were initiated. The exploratory training consisted of exploration and living on the table top. Over the 55-day preexperimental period *S*s received 20 exploratory experiences. On each run the animal, placed at the start of the elevated pathway, ran to the table where it spent the next 24 hr. The *S*s were never denied ready access to food and water. On the days when *S*s were not on the table top they remained in their home cages with food and water present.

Training and test trials.—At approximately 80 days of age, *S*s received training in a T maze. Each *S* was placed individually in the starting box of the maze, after having been satiated for food and water, and received two free choices to determine position preferences. The *S* was allowed to remain in the maze for 30 min. during which time all doors were raised. No food or water was in the end boxes during this familiarization training. The first free choice on the initial trial of the training series was noted, and one *S* who made both his preliminary choices and first free training choice to the same side of the maze was discarded. Eleven of the *S*s received training under 22-hr. food deprivation while the remaining ten were motivated by 22-hr. water deprivation. Prior to the initiation of the 22-hr. food deprivation each *S* was fed approximately 9 gm. of dog chow. During both the training and test trials water was present in one end box and food in the other. The first and third daily trials were free choices while the second and fourth were forced choices to the sides opposite to those selected on the immediately preceding trial. On the test trials *S*s who had been motivated for water during their training were run under successive motivations of 22 hr. of hunger, thirst, thirst, and hunger. Those who had been motivated by hunger during the training trials were thirsty on the first and fourth test trial and hungry on the second and third.

As Christie (1) had obtained no irrelevant-incentive learning in a control group that found food in one end box and nothing in the other, it was considered unnecessary to provide a similar control group in the present study.

Results

The number of *S*s that chose the correct side of the T maze on each of

the four test trials is presented in Table 1. The correct side of the maze is the side that contains the goal object for which *S* is motivated.

This table indicates that *Ss* in the hunger group demonstrated appreciably more irrelevant-incentive learning than did the thirst group. The hunger group, however, performed at a lower level of efficiency during the second and third test trials, during which time their motivation was similar to that existing during the training trials.

Another indication of the superiority of the hunger group over the thirst group in their ability to demonstrate irrelevant-incentive learning is the comparison of the percentages of both groups who shifted their spatial response on the first test trial. Of the 10 *Ss* in the hunger group who responded to the food side on the initial trial of the last day of training, 8 chose the water side when made thirsty. Only 2 of the 10 *Ss* in the thirst group responded appropriately when their motivation was shifted to hunger. This difference is significant beyond the .01 level of confidence and we may safely reject the hypothesis that the difference in performance between the hunger and thirst groups can be attributed entirely to chance variation.

TABLE 1

NUMBER OF *Ss* THAT CHOSE APPROPRIATE SIDE OF T MAZE ON INITIAL FREE-CHOICE TRIAL OF THE LAST DAY OF TRAINING AND DURING THE TEST TRIALS OF EXP. I

Training Motivation	*N*	Last Training Day	Test Trials			
			1	2	3	4
Hunger	11	10	9	7	8	11
Thirst	10	10	2	10	10	3

EXPERIMENT II

Procedure

Subjects.—The *Ss* for this experiment were 31 male albino rats of the same strain used in Exp. I.

Apparatus.—The T maze and exploratory apparatus were the same as those used in Exp. I.

Early experience.—Three groups of rats were reared under different conditions but all received exploratory experiences. Group A received 20 pre-experimental experiences with food and water present on the table top in a manner similar to the *Ss* in Exp. I except that these experiences lasted for only 1 hr. instead of 24 hr. On those pre-experimental days when *Ss* in this group did not receive exploratory training, they were given 9 gm. of food and allowed to drink for 1 hr. in their home cages. The *Ss* were highly motivated when placed on the runway for exploration as they had received only 9 gm. of food on the previous day in the home cage and had not been given water for 23 hr. Group B was reared under conditions of relative satiation. Food and water were always present in the home cages. This group also received 20 pre-experimental, 1-hr. exploratory experiences during rearing. During these 1-hr. periods in which food and water were available, no eating or drinking was observed as the *Ss* were satiated when placed on the runway for their exploratory trials. Group C was reared under conditions of satiation as was Group B. The exploratory experiences differed from those of Group B in that the food and water containers were removed from the table top prior to exploration. These *Ss* explored an empty table top and runway for 1 hr. on each of their 20 experiences.

Training and test trials.—All training in the T maze was identical with that of the hunger-trained group of Exp. I. After being trained for seven days under a 22-hr. hunger drive, all groups in this experiment were tested under successive motivations of 22 hr. of thirst, hunger, hunger, and thirst.

Results

The number of *Ss* that chose the correct side of the T maze on each of the four test trials is presented in Table 2. The correct side of the maze is the side that contains the goal object for which *S* is motivated.

Another measure of the amount of irrelevant-incentive learning is found in the percentage of *Ss* that shifted spatial responses on the first test trial

TABLE 2

NUMBER OF *Ss* THAT CHOSE APPROPRIATE SIDE OF T MAZE ON INITIAL FREE-CHOICE TRIAL OF THE LAST DAY OF TRAINING AND DURING THE TEST TRIALS OF EXP. II

Group	*N*	Last Training Day	Test Trials			
			1	2	3	4
A	11	11	8	11	11	8
B	10	10	3	10	10	4
C	10	9	5	9	10	5

under thirst motivation. Percentages of *Ss* shifting refer to the proportions of *Ss* that ran to the water side of the maze on the first test trial after running to the food side of the maze on the initial trial of their last day of training. Group A showed 72.7% shifting, Group B showed 30.0%, and Group C showed 44.4%. Group A, which was highly motivated during exploration, showed a high degree of irrelevant-incentive learning, whereas *Ss* that had been satiated during exploration (Groups B and C) showed a lesser amount. The difference in amount of shifting between Group A and Group B was significant at the .04 level of confidence. Differences between Groups A and C, and B and C were not significant ($p = .20$ and .53, respectively).

DISCUSSION

The present results confirm Christie's results regarding the effect of early exploratory experience on irrelevant-incentive learning in hunger-trained *Ss*. In Exp. I Christie's finding that hunger-trained *Ss* will show irrelevant-incentive learning if given exploratory experiences during rearing was confirmed.

It appears that the ability of *Ss* to demonstrate irrelevant-incentive learning is not a function of their ability to perceive the nature of their environment as is suggested by Christie's initial interpretation. If it is assumed that the early exploratory experience results in *Ss* noticing their environment, then it would be predicted that the thirsty and hungry *Ss* in Exp. I should perform at essentially the same level of efficiency during the test trials.[3] The fact that hungry *Ss* demonstrated significantly greater amounts of irrelevant-incentive learning than did thirsty *Ss* would be inconsistent with such an interpretation.

It is our contention that the important factor underlying the irrelevant-incentive learning demonstrated in these experiments is not a function of any "general ability" but rather a function of *how* the *S* responds to the unwanted goal object. Recent findings (**5, 6**) have indicated that when an *S* is very thirsty (22-hr. water deprivation) he tends to avoid dry food. In terms of the analysis offered (**5**), the *S* who is very thirsty is incapable of making fractional anticipatory eating responses to dry food and, consequently, the cues arising from these responses will *not* become conditioned to the food side, thus preventing the thirsty *Ss* responding appropriately during the hunger test trials. The *Ss* that are hungry during the training following early exploratory experiences are capable of making anticipatory drinking responses to the water and, consequently, the cues arising from these responses become conditioned to the water side, thus inducing the

[3] In a personal communication, Dr. Christie has noted that the ability of *Ss* to "perceive their environment" is not assumed to be solely a function of early exploratory experiences. The assumption that thirst is a stronger drive than hunger might account for the greater degree of irrelevant-incentive learning with hunger-trained *Ss*.

hungry *Ss*, when made thirsty, to respond appropriately.

Although the results of Exp. I suggest that early exploratory experience of the sort that was provided in these experiments, and in those of Christie (1), does not provide *Ss* with a general ability to learn the position of all irrelevant incentives, the same results provide no suggestions as to what factors within the exploratory experience permit *Ss* later, when hungry, to learn the position of water. To some extent this latter question is answered by Exp. II. Here it was found that *Ss* which were permitted to eat and drink during exploration demonstrated greater amounts of learning of the position of water when hungry. The *Ss* that ate and drank demonstrated 73% correct responses on the test trial, while those that did not showed 30–44% correct responses. At first glance the results of the hunger group of Exp. I may appear to be inconsistent with the above conclusion, since those *Ss* were satiated when placed in the exploratory situation and later demonstrated 80% correct responses. It will be recalled, however, that the exploratory periods during Exp. I lasted 24 hr. (as contrasted with a 1-hr. period during Exp. II) and consequently the *Ss* ate and drank during this period.

The theoretical question obviously is how does eating and drinking on a table top affect the learning of the position of water when hungry? Does something specific transfer to the T-maze situation? It is believed the answers to these questions are contained in the qualitative observations made when *Ss* were introduced into the exploratory situation. Originally each *S* is in a highly emotional state when placed on the elevated pathway. It freezes, squeals, defecates, and urinates profusely. After a few periods, *Ss* scamper down the elevated pathway with no obvious emotional responses.[4] Our first assumption is that the emotional responses are more completely and effectively extinguished when *Ss* are permitted to feed and drink on the table top. Such an assumption would be consistent with the results and their accompanying interpretation reported by Farber (2), i.e., the anxiety responses of *Ss* to a specific situation were reduced following their eating in that situation. It is assumed that an emotional or anxious *S* is responding largely to his own internal cues rather than external environmental ones, and consequently is unable to make fractional anticipatory responses to the cues from the irrelevant goal object.

The implications of the above line of reasoning would be that the failure of Spence and Lippitt (8) and Kendler (4) to find irrelevant-incentive learning was due to the fact that their preliminary handling techniques did not eliminate *all* emotional responses. However, it should be repeated once again that the elimination of emotional responses does not, of necessity, make an *S* capable of learning the position of irrelevant goal objects. The results of Exp. I indicated that thirsty *Ss*, although "emotionally adjusted," could not learn the location of dry food. It is hypothesized that these *Ss* did respond to the dry food but in a manner to avoid it and prevent the occurrence of fractional anticipatory goal responses.

Finally, it should be mentioned that the "exploratory experience" technique originated by Christie raises

[4] The fact that *Ss* often reach the table, wander about for a few moments, and then scamper back and forth down the elevated pathway is offered as evidence that they do not merely continue to avoid the elevated pathway but, rather, have had their emotional responses extinguished during the exploration process.

many interesting and important problems in the field of learning theory. According to our interpretation, Christie's results, as well as our own, are consistent with the theoretical analysis of irrelevant-incentive learning offered by Spence (7). The results are also in accord with the hypothesis suggested by Kendler and Levine (5), and Kendler, Levine, Altchek, and Peters (6), that animals who are strongly motivated by thirst cannot make anticipatory eating responses to dry food.

Summary

Groups of white rats were given varying types of exploratory experiences between the ages of 20 and 80 days. Upon reaching maturity these *S*s received training in a T maze under either hunger or thirst motivation. Following this training the drive state was switched and the number of correct responses to food or water was observed. Pre-experimental exploratory experiences were found to enhance irrelevant-incentive learning. In addition: (*a*) *S*s that eat and drink during any length of exploratory period, and then are trained under 22-hr. food deprivation, show 70%–80% correct responses when tested under a thirst drive; (*b*) *S*s that do not eat and drink during exploration, and then are trained under 22-hr. food deprivation, show 30%–40% correct responses when tested under a thirst drive; (*c*) *S*s that are trained under 22-hr water deprivation show approximately 20% correct responses when made hungry.

These results are interpreted in terms of (*a*) the "emotional-adjustive" effect of the exploratory experience and (*b*) the responses *S* makes to the irrelevant goal object.

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GENERALIZATION OF FEAR-MOTIVATED INTERFERENCE WITH WATER INTAKE

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Several experiments (e.g., **1, 3, 7**) have demonstrated that fear (anxiety) may serve to interfere with strongly reinforced response tendencies with which it is coexistent, despite the fact that the situation involves no apparent approach-avoidance conflict aspects, such as are present in certain of the studies of experimental neurosis (**5**). In some cases (**1, 7**), the interfered-with responses have been consummatory (eating, drinking, etc.). It has been suggested that interference with such reactions occurs through the presence of fear-motivated responses (e.g., crouching, face-washing, and also, perhaps, implicit reactions characteristic of fear) which are incompatible with the criterion response (**1**).

Since fear is defined, in most animal studies, as a conditioned form of the implicit reaction to noxious stimulation (pain), and since conditioned reactions are subject to variations in strength through stimulus generalization, it should be possible to control the degree of fear-motivated interference by manipulating the stimuli to which fear is conditioned. The present experiment tests this deduction.

METHOD

Subjects and apparatus.—The *S*s were 36 naive, female, albino rats from the colony maintained by the Department of Psychology of Newcomb College, Tulane University. All *S*s were between three and four months old at the beginning of the experiment.

The apparatus consisted of two parts: Apparatus A, in which the drinking behavior of *S*s was measured, and Apparatus B, in which the secondary (fear) drive was established and maintained. Both sections of the apparatus were in the same experimental room, and were separated by a wooden partition.

Apparatus A was a rectangular box with a wood floor and wire-mesh top. It was 12 in. long, 6½ in. wide, and 7½ in. high in its inside dimensions. The walls and floor were painted black. In the wall at one end of the box a small opening was made to permit the insertion of the orifice of a graduated drinking device.

Apparatus B, previously employed by Amsel (**1**) in an experiment similar to the present one, was a rectangular box with a grid floor and glass top. Its inside dimensions were 20 × 9 × 7 in. The walls were painted white, and white paper was kept under the grid floor at all times. The grid floor was constructed of 3/16-in. brass rod spaced ½ in. apart. Alternate grid bars were wired and connected to the terminals of an instrument which produced the shock employed. The shock-producing instrument was a constant current DC supply which delivered short pulses of shock at the rate of five shocks per second. The pulsating shock was accompanied by a sharp clicking sound made by a relay in the shock circuit. This clicking served as an important stimulus in the experiment.

Habituation period.—For 14 days *S*s were handled by *E* and adjusted to the drive regimen. During this period, the following schedule was set up: 7 P.M.—*S*s were removed from the home cages to individual feeding cages containing 2 gm. of Purina Dog Chow but no water; 7:30 P.M.—*S*s were taken to the experimental room where they were put on a table and handled for 30 min.; 8 P.M.—*S*s were returned to the individual feeding cages for 1.5 hr. and were allowed 6 gm. of food and ad libitum drinking. Throughout the remainder of the experiment this same sequence was followed each day except that the experimental manipulations replaced the 30 min. of handling.

Pretreatment measurement of water intake.—Once each day for 33 days the amount of water intake in 5 min. was measured in Apparatus A for each *S* under the drive conditions indicated above. The drinking device permitted measurement of water intake to the nearest 1/10 ml. The *S*s were run in squads of approximately seven, the order within each seven varying randomly from one day to the next. After 33 days, an apparent maximum in the mean drinking curve seemed to have been reached.

Experimental grouping of subjects.—The *S*s were now divided into three groups, with 12 in

each group, equated for level of water intake on the last of the preliminary trials. The groups were assigned at random to the three experimental conditions. They were differentiated according to (*a*) the kind of treatment which they would be given during a four-day period preceding a further period of water intake measurements, and (*b*) stimulus conditions to prevail during this second series of drinking trials. These treatments were designed to provide for the presence of varying degrees of fear during the subsequent period of testing for water intake.

Treatment during four-day period in Apparatus B.—During this part of the experimental procedure, water intake in Apparatus A was not permitted. Each *S* of Groups II and III was shocked in Apparatus B according to the following procedure: (*a*) *S* was placed in Apparatus B and after 20 sec. a shock of 60-v. intensity was applied through the grid floor for 20 sec.; (*b*) the shock was turned off for 20 sec. and was then reapplied for 20 sec., and this was repeated until five 20-sec. shock periods had occurred; (*c*) following the last 20 sec. of shock, *S* remained in the apparatus for 20 sec.; (*d*) the door was opened and *S* was allowed to escape. If after 30 sec. *S* had not removed itself from Apparatus B, continual shock was put on the grid until *S* escaped. The 20-sec. shock periods were marked by a very sharp clicking sound made five times per second by a relay in the shocking equipment. Group I (the nonfear control) *S*s were also put into Apparatus B but no shock was administered, although the clicking sound of the shocking instrument was introduced as in Groups II and III.

The above procedure was designed to condition a fear response to the various cues in Apparatus B (white walls, grid floor, clicking sound, etc.). In order further to differentiate Apparatus B from Apparatus A, Apparatus B was illuminated by a 100-w. lamp placed 2 ft. above it. This increased illumination also served as a cue for the conditioning of fear.

Posttreatment measurement of water intake.—This period followed immediately the four-day period outlined above and served to test the effect upon water intake of the various experimental conditions. On each day of this period, which lasted 18 days, each *S* was allowed to drink in Apparatus A for 5 min. as in the preliminary trials. The thirst drive conditions were the same as before. But before drinking, each *S* was placed in Apparatus B for 40 sec. No shock was administered, but the clicking noise was present for the last 20 sec. Each *S* was then removed from Apparatus B and put immediately into Apparatus A for measurement of water intake. The auditory (clicking) cue was present for Group III while in the drinking situation, but not for Groups I and II. During these test trials, also, the level of illumination was increased in Apparatus A, by allowing the lamp above the adjacent Apparatus B to remain on. This provided a generalized fear-producing cue which was common to Groups II and III, and which was also present for the nonfear, control group.[1]

Results and Discussion

The mean water intake on each trial was calculated for the three experimental groups. These means for the 33 pretreatment and 18 posttreatment drinking trials are presented graphically in Fig. 1. It is apparent from an inspection of the graph that the drinking curves for the three groups are quite similar during the preliminary measurement of water intake. However, a comparison of the level of water intake on the last days of the pretreatment trials with that on the initial posttreatment trials reveals a marked difference between the three groups. The mean water-intake curve for Group I (control) shows no important change. However, the curves for Group II and Group III show definite drops. The mean water intake on Day 33 for the 12 *S*s in Group II was 6.07 gm., while on the first posttreatment trial it was 4.40 gm. An even sharper drop is noted in the curve for the 12 *S*s of Group III. The mean water intake on Day 33 of the preliminary period was 6.15 gm., that on Day 1 of the test period was 1.60 gm.

A "before" score and an "after" score were calculated for each *S* to determine the significance of these observed differences. The "before" score was the mean water intake in milliliters for each *S* for the last 5 of the 33 pretreatment trials (days); the

[1] In a previous experiment (1) a control group showed no effect from the presence of the clicking sound during drinking periods, when, the clicking had not been associated with shock. It was felt unnecessary to repeat this control here, since the conditions of the two experiments are almost identical.

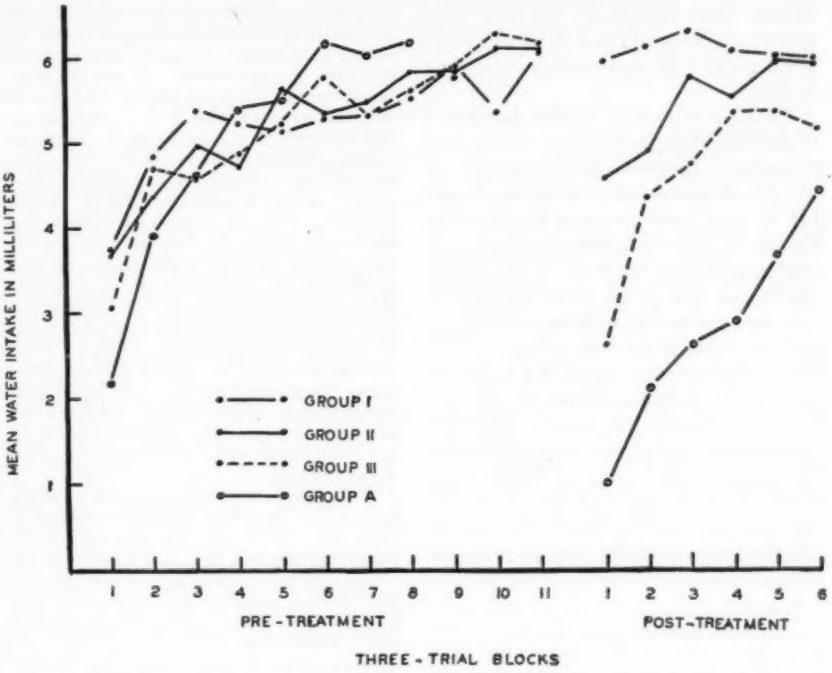

FIG. 1. Mean water intake on the pretreatment and posttreatment trials for the three groups from this experiment and one (Group A) from an earlier study

"after" score was the mean of the first five of the 18 posttreatment trials (days). The means and *SD*'s of these scores are presented in Table 1, along with mean difference scores obtained by taking the mean of the differences between the "before" and "after" means of each *S*.

The difference scores summarized in Table 1 were the criterion scores for a simple analysis of variance. Before this was done, a constant was added to each score to remove negative values, and Bartlett's test of homogeneity was applied to the three groups of scores. The chi-square value obtained was .97 ($.70 > p > .50$). From the analysis of variance, an F of 18.52 was obtained. This greatly exceeds the value of F required at the .01 level of confidence.

In view of the significant F obtained, the reliability of the differences between the drops in drinking level of adjacent test curves could be evaluated. A comparison of the scores of Groups I and II yielded a t of 3.65 (for $p = .01$, $t = 2.81$ with 22 *df*).

TABLE 1

WATER INTAKE IN MILLILITERS

Group	Pretreatment		Posttreatment		Difference	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
I	5.85	1.37	6.02	1.33	−.17	1.00
II	6.19	1.61	4.63	1.35	1.56	1.21
III	6.18	1.11	3.24	.92	2.94	1.36

When the difference between the means of Groups II and III was evaluated, a t of 2.50 was obtained ($.05 > p > .01$).

Finally, attention should be called to the fact that, as the test trial period progresses, there is a gradual return of the drinking curves of Groups II and III to their pretreatment level. The Group II curve has, apparently, recovered completely by the last test trial; the Group III curve does not appear to have returned completely to its final pretreatment level. In order to test this last statement another t test was run on the difference between the last five trials of the preliminary drinking and the last five trials of test drinking for Group III.[2] A t of 2.76 was obtained ($p = .02$). Thus, it would appear that some depression of the drinking curve for this group remains even at the end of the test trial period.

It would seem reasonable to interpret these results as showing the effect on drinking behavior of fear (anxiety) with three levels of fear operating. The *Ss* in Group III were subjected to a specific and controlled fear-producing cue (clicking) during the test drinking in addition to other more generalized cues. The *Ss* of Group II were, presumably, less fearful during the test drinking trials, since the important auditory cue present in Group III was absent here. Hence Group III shows a very marked drop in drinking at the beginning of the test period whereas Group II shows a lesser but still significant drop.

We may, with some caution, compare the present data with those obtained by Amsel (1) in a similar experiment. The open circles in Fig. 1 (Group A) represent mean drinking in 5 min. on 24 pretreatment and 18 posttreatment days. The *Ss* in his study were conditioned to fear (anxiety) between preliminary drinking and test trials, in *the same compartment* in which drinking behavior was measured (Apparatus B of the present experiment). It is therefore reasonable to assume that a maximum amount of fear was present at the beginning of the postshock drinking sessions. The last point of the pretreatment mean drinking curve for this group, representing the performance of the last three days, was at approximately the same level as the last points of the corresponding curves for the present experiment. The same drinking device was used in both studies. A four-day shock period was also employed, during which time *Ss* received two shock trials of 5-sec. duration per day, separated by a 5-sec. interval. The shock intensity differed in the two studies: the earlier one employed .1 mamp. and the present one .2 mamp. During the postshock period, *Ss* were reintroduced into the apparatus without further shock and allowed to drink for 5 min. in the presence of all the cues which had accompanied shock (including the clicking sound of the present experiment). Inspection of Fig. 1 shows that the mean drinking curve following the four-day shock period in the Amsel study starts lower and develops in the same manner as the two curves of our experimental groups. The initial posttreatment points of the four curves in Fig. 1 may be taken as representing a gradient of fear-motivated interference with the consummatory reaction of drinking.

Since, in this experiment, the conditioning of fear was entirely separate from the training to drink, the interference with drinking and its generalization would seem to depend upon the strength of fear evoked by the cues present, rather than on any direct effect upon drinking of these cues. In some other studies concerned with generalization effects on fear-motivated responses (2, 4) the conditioning of fear presumably accompanies the learning of some other response. This second response is later measured to test for generalization effects, so that it is not possible to determine whether the generalization is in the fear response, or in the fear-motivated response, or in both.

A study by May (6) includes an experiment on generalization of fear which bears some similarity to the present experiment. He reports an experiment in which a barrier-crossing response, elicited at first by shock, was later made to a buzzer which had been paired with shock in the absence of opportunity to cross the barrier. During later test trials, barrier crossing was also evoked by other auditory stimuli (tapping on glass, clicking sound). Since the tapping sound evoked more crossings than the original CS, there is some doubt as to a strict generalization interpretation of these data. Be that as it may, there are two major differences between May's experiment and ours: (*a*) he demonstrated generalization of fear in terms of the spread of its activating properties to stimuli other than the original CS; we have demonstrated it in terms of decreases of its interfering effect; and (*b*) he measured the strength of an instrumental response previously made to shock as an indicant of the degree of generalization, while we have

[2] Since one *S* of Group III died before the end of the experiment, this analysis is done for only the remaining 11 *Ss*.

measured a consummatory reaction which has been associated with neither shock (pain) nor fear.

Summary

Thirty-six rats were trained to drink water during a 5-min. period in a controlled situation, until level of water intake for the group reached a fairly stable maximum. They were then split into three groups, equated for level of water intake, and subjected to a four-day period, in a different situation, wherein two of the groups were shocked and the third group was not. Following this treatment, the groups were again put into the drinking situation for 5 min. a day, with some of the cues from the shock situation—but no shock—present.

The results show that level of water intake did not change significantly in the group that was never given shock. In the two shock groups, a drop in level of water intake was observed following the shock treatment, the amount of drop being related to the specificity of anxiety-producing cues present in the drinking situation. These data, along with those from a previous experiment where anxiety was conditioned to the drinking situation, suggest a gradient of anxiety-motivated interference with the consummatory behavior, i.e., the greater the similarity of the drinking to the shock situation, the greater the drop in level of water intake.

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THE GROWTH OF LEARNING DURING NON-DIFFERENTIAL REINFORCEMENT[1]

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It has proved to be quite difficult to design experiments in the field of learning which would lead to antithetic predictions by the various contemporary theories. The following experiment, which concerns itself primarily with the growth of learning during nondifferential reinforcement does, however, lead to diverse predictions by the theories of learning advocated by Hull and Bitterman. A brief glance at these contemporary theories along with the theory of Spence will serve as an adequate introduction to the problem.

A fundamental assumption in Hull's theory of learning is that habit strength grows in a negatively accelerated manner as a function of the number of reinforcements. From this assumption it follows that the rate at which differences in strength between competing response tendencies grow should be related inversely to the initial strength of the individual tendencies. In his last work, *A Behavior System* (**3**, p. 29), Hull has worked through this deduction for two hypothetical cases differing in the initial strength of the competing response tendencies for a simple trial-and-error problem: in Case I ($_sE_{R+} = {}_sE_{R-} = 2.5\sigma$) and Case II ($_sE_{R+} = {}_sE_{R-} = 4.5\sigma$). His analysis reveals that 25 trials would be required to reach a .978 dominance of $_sE_{R+}$ in Case II as compared with only 10 trials in Case I.

[1] Adapted from a dissertation submitted in partial fulfillment of the requirements for the doctor of philosophy degree in the Department of Psychology, The University of Texas. The writer is greatly indebted to Professor Karl M. Dallenbach for his generous aid.

Findings by Siegel (**5**) in an experiment with white rats on a T maze and Maltzman and Morrisett (**4**) in an experiment on the solution of anagrams by human *Ss* have been offered in support of Hull's deduction. It should be pointed out, however, that in both the Siegel and the Maltzman and Morrisett experiments the *Ss* had to deal principally with problems involving response selection.

Bitterman, who has vigorously championed the importance of perceptual organization in learning, has, up to the present moment, not published any rigorous statement of his own theory. In a recent paper, however, in discussing the Siegel and Maltzman and Morrisett experiments, he pointed out, "As Siegel noted, such data are difficult to reconcile with the concept of perceptual learning, since increased experience with a situation should, all other things equal, provide greater opportunity for perceptual development" (**1**). The findings of this study by Bitterman, Calvin, and Elam (**1**) were cited as evidence against the position of Hull and in support of the position of Bitterman.

Although Hull states that his beliefs concerning the growth of discrimination learning are "essentially the writer's interpretation of Spence's extension and formalization of Pavlov's analysis of discrimination learning," there are vast differences between Spence and Hull on the shape of the generalization curves, function of inhibition, etc. While a discussion of these differences is long overdue, space will not permit such a discussion here.

Spence does give a summary of his position in the 1936 paper, which illustrates some of the differences between himself and Hull which are most relevant to the present experiment. Spence states:

> (1) The strength of an S . . . R connection is increased when followed by reward, i.e., the occurrence of a final or consummatory response, by an increment, 'I,' which varies according to the function $I = \frac{K}{e^{(s-s_0)^2/2t^2}}$ in which K and t are constants dependent upon the individual learner, and s is a variable representing the strength of the S . . . R connection at any point in the learning process.
>
> (2) The strength of an S . . . R connection is decreased or weakened by failure of reward by a decrement 'D,' which varies according to the function $D = as - b$, in which a and b are constants for an individual learner and s is a variable representing the strength of the S . . . R connection at any point in the learning process (6, p. 433).

Thus the Hull and Bitterman theories would lead to divergent predictions regarding the effect of nondifferential reinforcement on the growth of learning. Hull would predict that the less nondifferential reinforcement, the quicker the learning. Bitterman would predict just the reverse: the more nondifferential reinforcement, the quicker the learning.

Spence, by making the proper assumption concerning the level of s and by selecting the proper constants for K and t, can handle any results obtained.

The present experiment was undertaken primarily to provide a test of Hull's and Bitterman's theories concerning the growth of learning. A second hypothesis which was suggested by Professor Bitterman was also tested. The effect of punishment occurring during nondifferentially reinforced experience was studied to determine whether punishment, by forcing the animals to slow down their jumping and presumably pay more attention to the stimulus cards, would facilitate learning by furthering the growth of perceptual organization during the course of nondifferential reinforcement.

Apparatus and Procedure

Sixty-four experimentally naive white rats of the Wistar strain were used in the experiment. The *S*s were approximately 3 mo. old at the beginning of the experiment. A conventional two-window Lashley jumping stand was used. The windows were 5 in. square. The entire apparatus was painted flat black. The stand was equipped with a burlap net where *S*s fell if they made an incorrect choice during a trial. Wet mash, which served as the reward for correct choice, was placed in an enclosure at the rear of the jumping stand.

During the preliminary training, all *S*s were maintained on a 24-hr. feeding schedule. For two weeks they were handled and fed in the apparatus. They were then trained to jump gradually increasing distances from the jumping stand to open windows until all *S*s were jumping a distance of 9 in. without any assistance from *E*. Manual guidance was employed to insure equal experience with both windows. Mild shock was used to initiate jumping during early stages of the preliminary training. The stimulus cards used were the following kinds: two homogeneous mid-gray cards and four ½-in. black-and-white striped cards. Two of the cards were vertically striped and two were horizontally striped.

After all *S*s were jumping freely, they were randomly divided into two groups. Group I consisted of 32 *S*s who experienced no punishment during their nondifferentially reinforced training. During the first stage of the experiment, all *S*s of Group I were given 12 reinforced trials per day for a period of 16 days. During *S*s' experience with striped cards, both horizontally- and vertically-striped cards were presented simultaneously and each appeared equally often in the left and right windows. The number of reinforcements on each card and each window was equated by manual guidance. For each *S*, half of the trials were free and half were forced, and each jump was rewarded with wet mash. Time taken on the stand before jumping was recorded with a stop watch on Days 5, 10, and 15 during the first stage of training.

Group II consisted of 32 *S*s whose training was identical with that of Group I, except that on two trials each day each rat jumped to a locked window. These two trials were distributed randomly among the series of 12 reinforced trials and manual guidance was used to insure

equal punished experience with both cards in both windows.

Groups I and II were each divided into four subgroups of eight *S*s which will be referred to respectively as IA, IB, IC, and ID for the nonpunished group, and IIA, IIB, IIC, and IID for the punished group. Groups IA and IIA had 16 days of nondifferentially reinforced training on gray cards and no nondifferentially reinforced training on striped cards. Groups IB and IIB had 12 days of nondifferentially reinforced training on gray cards followed by four days of nondifferentially reinforced training on striped cards. Groups IC and IIC had 8 days of nondifferentially reinforced training on gray cards followed by 8 days of nondifferentially reinforced training on striped cards. Groups ID and IID had no nondifferentially reinforced training on gray cards and 16 days of nondifferentially reinforced training on striped cards (see Table 1).

In the second stage of the experiment, *S*s of all subgroups were trained on a simultaneous discrimination between the horizontally and vertically striped cards. For half of the *S*s in each subgroup the vertically striped card was positive and for the other half the horizontally striped card was positive. The position of the positive card was alternated according to a Gellerman series (2). Ten trials per day were given by the correction method. Each trial consisted of a series of one or more jumps terminating when a correct choice was made by the animal. An *S* was permitted a maximum of three errors on any trial, after which it was manually guided to the correct window. The criterion of learning was two successive errorless days.

Results and Discussion

The first step in the consideration of the data consisted of two analyses of variance, one of initial errors and one of total errors. Both of the major variables, punishment and experience with striped cards, plus a first-order interaction between them, were significant beyond the .01 level for both total errors and initial errors. Bartlett's test for homogeneity of variance was applied and the resulting chi squares were not significant for either analysis.

These findings were broken down in terms of mean scores for the subgroups in Group I in order to study the effect of varying amounts of nondifferential reward without any punishment. The mean scores for initial and total errors are shown in Table 1. A glance at the learning curves given in Fig. 1 and 2 reveals that one *S* in Group IC was still jumping to a fixed position at the end of 18 days when the experiment was terminated. This *S* thus caused a marked skewness in the shape of the distribution of scores in Group IC. Because of this skewness and also because of the difficulty, with only eight *S*s in each subgroup, of satisfying the *t* test assumptions of trait normality and homogeneity of variance, Wilcoxon's nonparametric method (7) was used for testing the difference between individual subgroups in Group I. Only three differences were significant. The difference between IB and

TABLE 1

Mean Error Scores for All Conditions and Combinations of Conditions

Schedule of Nondifferential Reinforcement			Main Group I No Punishment			Main Group II 2 Trials Punishment			Combined Groups I and II		
Group	Days on Gray Cards	Days on Striped Cards	*N*	Initial Errors	Total Errors	*N*	Initial Errors	Total Errors	*N*	Initial Errors	Total Errors
A	16	0	8	10.9	18.5	8	23.3	58.9	16	17.1	38.7
B	12	4	8	15.5	24.3	8	39.6	105.8	16	27.6	65.0
C	8	8	8	21.2	56.6	8	26.4	61.4	16	23.8	59.0
D	0	16	8	10.5	16.3	8	18.3	27.0	16	14.4	21.6
Total by main groups			32	14.5	28.9	32	26.9	63.3			

ID in initial and total errors was significant beyond the .05 level of confidence. The difference between IC and ID in total errors was also significant beyond the .05 level.

To ascertain the effect of varying amounts of nondifferential reward and punishment, comparisons were made among the various subgroups of Group II. The mean scores for initial and total errors are shown in Table 1. Figures 3 and 4 indicate that two *Ss* in Group IIB, one in Group IIA, and one in Group IIC were still jumping to a fixed position at the termination of the experiment. Wilcoxon's nonparametric method (**7**) was used to test the differences between the subgroups in Group II. Only one difference was significant. Subgroup IIB vs. IID for total errors was significant beyond the .01 level of confidence.

When subgroups IA and IIA, IB and IIB, IC and IIC, and ID and IID were combined in order to study the effect of varying amounts of nondifferential reinforcement merely as a temporal variable, the mean scores shown in Table 1 were found. Again using Wilcoxon's nonparametric method the difference between the combined A groups and the combined B groups for both initial and total errors was significant beyond the .05 level of confidence. The difference between the combined B and D groups was significant beyond the .05 level for initial errors and the .01 level for total errors. The difference between the combined C and D groups for total errors was likewise significant beyond the .01 level of confidence.

When the Group I *Ss* were compared with the Group II *Ss*, in order to ascertain the effect of punishment, the Group I *Ss* were consistently better. The mean score for all the Group I *Ss* combined was 14.5 for initial errors and 28.9 for total errors. The mean score for all the Group II *Ss* combined was 26.9 for initial errors and 63.3 for total errors. The difference between IA and IIA was signifi-

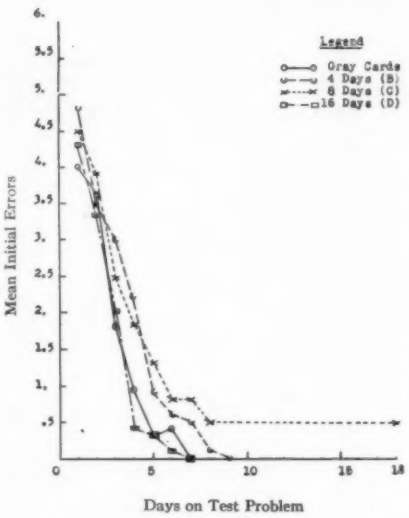

FIG. 1. Initial errors of subgroups of Group I

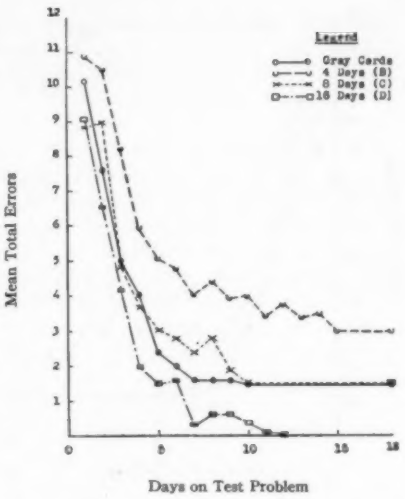

FIG. 2. Total errors of subgroups of Group I

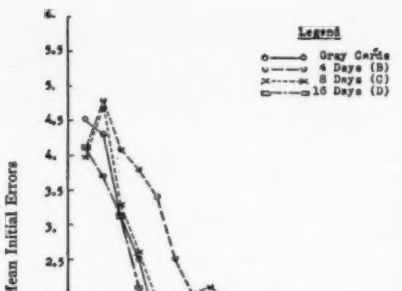

FIG. 3. Initial errors of subgroups of Group II

cant beyond the .05 level of confidence, using Wilcoxon's nonparametric method (7), for both initial and total errors. The difference between IB and IIB was significant beyond the .05 level of confidence for initial errors and the .01 level for total errors. The difference between ID and IID was significant beyond the .01 level of confidence for both initial and total errors. The Group I *Ss*, taken as a whole, were significantly better than the Group II *Ss*. This difference was significant beyond the .01 level of confidence for both initial and total errors.

The results of this experiment thus fail to support predictions made from either Hull's or Bitterman's theories of learning. From Hull's theory it follows that the groups should have performed in the following manner: Among the nonpunished groups, IA should have done the best, followed by IB, IC, and ID. Among the punished groups, IIA should have done the best, followed by IIB, IIC, and IID. The actual results (see Table 1) were: Among the nonpunished groups, ID did the best, followed by IA, IB, and IC. Among the punished groups, IID did the best, followed by IIA, IIC, and IIB. Although some of these differences are not significant (see Table 2), the consistently significant differences between the D groups and their respective B and C groups are directly contradictory to the results that would follow from Hull's theory.

From Bitterman's position it follows that among the nonpunished groups, ID should have done the best, followed by IC, IB, and IA. Among the punished groups, IID should have done the best, followed by IIC, IIB, and IIA. The actual results, as noted above, were ID, IA, IB, IC, and IID, IIA, IIC, and IIB, respectively. Again, although some of these differences are not significant (Table 2), the excellent performance of Groups IA and IIA is directly contradictory to the results which would be expected from Bitterman's theory.

The results pertaining to the effect of punishment fail to support the

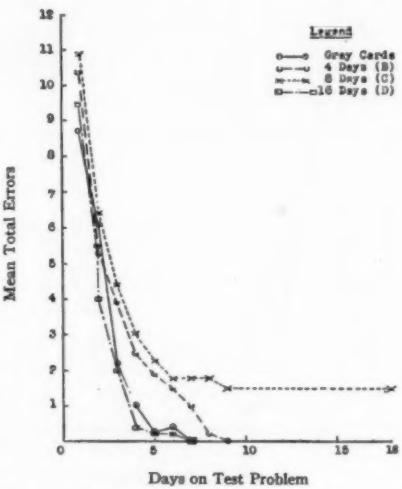

FIG. 4. Total errors of subgroups of Group II

hypothesis that forcing *Ss* to slow down their jumping during predifferentially reinforced training should facilitate learning by furthering the growth of perceptual organization.

The time trials for Groups I and II gave the following results: On Day 5, *Ss* in Group II were jumping more slowly than *Ss* in Group I ($p = .01$). The two groups, however, did not significantly differ on Day 10 or 15. In spite of the longer time taken by the Group II *Ss*, the Group I *Ss* performed consistently better. The fact that Group IA was superior to Group IIA indicates that punishment introduces some extraneous factor, i.e., frustration, rigidity, etc., which could easily have masked any facilitation of learning in the Group II *Ss*. Although these results certainly do not support the hypothesis that forcing *S* to take more notice of the stimuli will facilitate learning, the negative findings cannot be considered as conclusive.

TABLE 2

COMPARISONS OF GROUP MEANS ON INITIAL AND TOTAL ERROR PERFORMANCE

Groups Compared	Differences in Initial Errors	Differences in Total Errors
IA vs. IB	4.6	5.8
IA vs. IC	10.3	38.1
IA vs. ID	.4	2.2
IB vs. IC	5.7	32.3
IB vs. ID	5.0*	8.0*
IC vs. ID	10.7	40.3*
IIA vs. IIB	16.3	46.9
IIA vs. IIC	3.1	2.5
IIA vs. IID	5.0	31.9
IIB vs. IIC	13.2	44.4
IIB vs. IID	21.3	78.8**
IIC vs. IID	8.1	34.4
IA vs. IIA	12.4*	40.4*
IB vs. IIB	24.1*	81.5**
IC vs. IIC	5.2	4.8
ID vs. IID	7.8**	10.7**
IA + IIA vs. IB + IIB	10.5*	26.3*
IA + IIA vs. IC + IIC	6.7	20.3
IA + IIA vs. ID + IID	2.7	17.1
IB + IIB vs. IC + IIC	3.8	6.0
IB + IIB vs. ID + IID	13.2*	43.4**
IC + IIC vs. ID + IID	9.4	37.4**

* $p < .05$.
** $p < .01$.

The results of this study indicate that the growth of learning is not a simple function of either the growth of habit strength or perceptual organization. It seems to be a complex process, best described by a theory which attempts to take into account the various factors operating and the interactions among them. Spence's theory can adequately handle all our results by making the proper assumptions concerning the level of s and by selecting the proper constants for K and t. The objection raised by the perceptual theorists that this is an *ad hoc* formulation that "can explain everything but predict nothing" does not seem justifiable to the author. A series of experiments is planned to test extensively the adequacy of Spence's theory. It appears obvious, however, that both Hull's and Bitterman's theories of learning must be radically revised in order to account for the findings of this experiment.

SUMMARY

Sixty-four white rats were trained in a conventional two-window Lashley jumping stand for a period of 16 days. For half the animals (Group I) all jumps were rewarded. The other half (Group II) had two punished trials (locked cards) randomly interspersed among their rewarded trials. The *Ss* of both groups were further subdivided on the basis of whether they were given 0, 4, 8, or 16 days of experience with horizontally- and vertically-striped cards. All *Ss* in both groups were trained on a simultaneous discrimination between the horizontally- and vertically-striped cards. Two analyses of variance were computed, one for total errors and one for initial errors. Both major variables—punishment and experience with striped cards—were significant beyond the .01 level. A breakdown of these findings revealed that the Group I *Ss* were consistently superior to those of Group II. A more detailed analysis of the performance of individual sub-groups showed that the Group

I *S*s performed in the following manner: Group ID did the best, followed by IA, IB, and IC. The Group II animals performed in this manner: Group IID did the best, followed by IIA, IIC, and IIB.

These results fail to support predictions based on either the Hull or Bitterman theory of learning. Spence's theory adequately accounts for all the data, but this experiment did not provide a crucial test for his formulation.

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EXTINCTION OF A PARTIALLY AND CONTINUOUSLY REINFORCED RESPONSE WITH AND WITHOUT A REWARDED ALTERNATIVE[1]

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The strength of an instrumental response can be measured by its resistance to change (*a*) in extinction where reward is withheld or (*b*) in retraining where a different response is rewarded (7). It has been clearly established that partial reinforcement induces a greater resistance to extinction than continuous reinforcement (4). This generalization, however, has been based solely on studies in which response strength has been assessed by the performance in the absence of reinforcement. The purpose of the present investigation is to test the validity of this generalization when reward is withdrawn from an original response and the organism learns a new instrumental sequence.

METHOD

Subjects and maintenance.—The *S*s were 58 experimentally naive male hooded rats of 90–120 days old from the colony maintained by the Psychology Department of the University of California at Los Angeles. Fifteen additional *S*s were discarded after varying amounts of training due to excessive timidity, sickness, and experimental error. The *S*s subsisted on Little Friskie pellets supplemented by slight amounts of lettuce twice a week.

Apparatus.—The cross-shaped alley maze embodied a runway with extended side alleys (see Fig. 1). The runway was painted flat gray and the end box was differentiated by having plastic window screen on the floor. A guillotine door permitted *S* to enter the runway path and a light metal push door gave it access to the runway goal box.

The side arms of the maze were identical in construction to the runway end box and were painted black and white. By moving the runway back or forth several inches and raising Plexiglas guillotine doors at the juncture of the runway and side arms the *S*s were confronted with a black-white discrimination problem.

Except for the starting box and the final 9 in. of the goal boxes the maze was covered with fine mesh hardware cloth. The starting box had a hinged heavy gauge hardware cloth cover and the extreme ends of the goal compartments were covered by hinged Plexiglas panels. The apparatus was placed on a large table 30 in. high and illuminated from above by a 300-w. lamp at each end of the runway. No effort was made to eliminate extra-maze cues but a large number of food pellets was distributed over the far corners of the table to control food odors.

Procedure.—The initial handling and the establishment of a 22-hr. hunger cycle extended over a 10-day period. The rats were gentled, given nonrewarded exploration in a 4-ft. gray alley, and put in and out of individual handling cages and cardboard boxes. One-half hour after each daily session they were fed for 1 hr. in their group living cages. This feeding procedure was

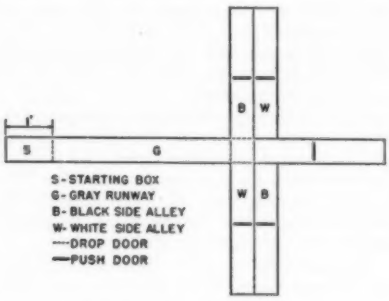

FIG. 1. Floor plan of maze

[1] A portion of a dissertation submitted to the graduate division of the University of California at Los Angeles in partial satisfaction of the requirements for the degree of Doctor of Philosophy. The writer would like to express his sincerest thanks to the doctoral chairman, Dr. H. C. Gilhousen, and the committee members, Drs. I. Maltzman, J. P. Seward, F. Fearing, C. Panunzio, and M. V. Seagoe, for their assistance and encouragement throughout the course of the investigation.

maintained during the course of the study and water was always available in the home cages.

Next, *Ss* were subjected to preliminary training in the maze. On the first day groups of four to six *Ss* had two 15-min. exploratory sessions. On the following two days *Ss* received two individual trials in which they were permitted to explore all the alleys, but were removed upon entrance into the runway goal box. After all *Ss* in each group had completed these trials they were carried singly to the runway goal box and allowed to eat for 2 min. During the next two days they underwent five trials per day. The first trial was a forced run into either side alley. After 15-sec. confinement in the side alley goal box *S* was returned to his individual handling box. The second trial was a forced run to the side opposite from that chosen on trial one. Then three runway trials were administered, each rewarded with a single standard-sized Little Friskie pellet ($\frac{1}{4}$ in. long, $\frac{1}{8}$ in. in diameter). On the final two days of maze adaptation the procedure was similar except that four runway trials were given. On the last four days and throughout the remainder of the study the trials were spaced by a 15-sec. interval, the rats were guided into the different alleys by dropping the appropriate doors at the maze juncture, and the runway was shifted back and forth in a counterbalanced order (2) to equalize the black-left, white-right and white-left, black-right combinations on the side arms.

The original instrumental response, traversing the runway, was conditioned under three reinforcement conditions: Group 100-4 received 40 rewarded trials in four days, Group 100-8 received 80 rewarded trials in eight days, and Group 50 received 80 trials half of which were reinforced in an eight-day period. Prior to the ten daily runway trials Groups 100-8 and 50 had one nonrewarded side alley run which was free to either side on the first day, forced to the opposite side on the second day, and so on. By the forced trial procedure and the counterbalanced shifting of the runway each *S* obtained an equal number of entries into each side alley under both brightnesses. Group 100-4 had two side alley trials daily making their total the same as that of the other groups.

On all trials response latencies were recorded. As *E* raised the starting door he depressed a foot pedal activating a standard timer. He stopped the clock when *S*'s hind feet crossed a line 2 ft. from the starting box. If the *S* retraced, the clock was reactivated until the mark was passed again in its path down the alley.

The schedules of partial reinforcement had the following restrictions: (*a*) Five runs were rewarded daily and five were not. (*b*) The first and last trial were always reinforced. (*c*) No more than two rewarded or nonrewarded trials occurred in sequence.

A different pattern was employed each day but the same one was used for all *Ss* in Group 50. On the nonreinforced trials the food dish was removed and *S* was confined in the goal box for 15 sec.

On the day after the completion of the runway training five control *Ss* from each reinforcement condition began regular extinction. The remainder of the *Ss* (Group 100-4 $N = 16$; Group 100-8 $N = 12$; Group 50 $N = 15$) were subjected to the experimental treatment of retraining. The purpose of the control experiment was to determine the order of extinction of the runway response which had been conditioned previously under the three reinforcement conditions, while the purpose of the experimental treatment was to determine the effects of a rewarded alternative upon extinction.

The first trial on the initial extinction day was a forced trial to either side alley. The second trial was a rewarded "warm-up" run down the runway, and then four extinction trials were given in which *S* had access only to the runway and its empty goal box. On the following three days five runway extinction trials were administered. Each trial was separated by a 15-sec. interval and *Ss* were confined for 15 sec. in the empty runway goal box.

The first two trials in retraining were the same as those for the control *Ss*. After the second trial all the choice-point doors were raised and the food was shifted to either the white or black side arm. Half of the *Ss* in each reinforcement condition were required to find the food in the alley corresponding to their preferred brightness and half in the alley opposite to their preferred brightness. These preferences were determined by a tabulation of the free side alley choices in pretraining and training. If in retraining *Ss* entered the runway end box (hereafter referred to as a "fixation error") or the incorrect side alley ("discrimination error"), they were confined in the goal boxes for 15 sec. The retraining procedure was continued for ten days at the rate of five trials per day. At this point mastery of the discrimination response was indicated by the attainment of an arbitrary group performance criterion of 90% correct responses on two successive days.

Results

In summarizing the findings we shall consider in order the acquisition of the original runway response, the control groups' extinction performance, and the retraining behavior of

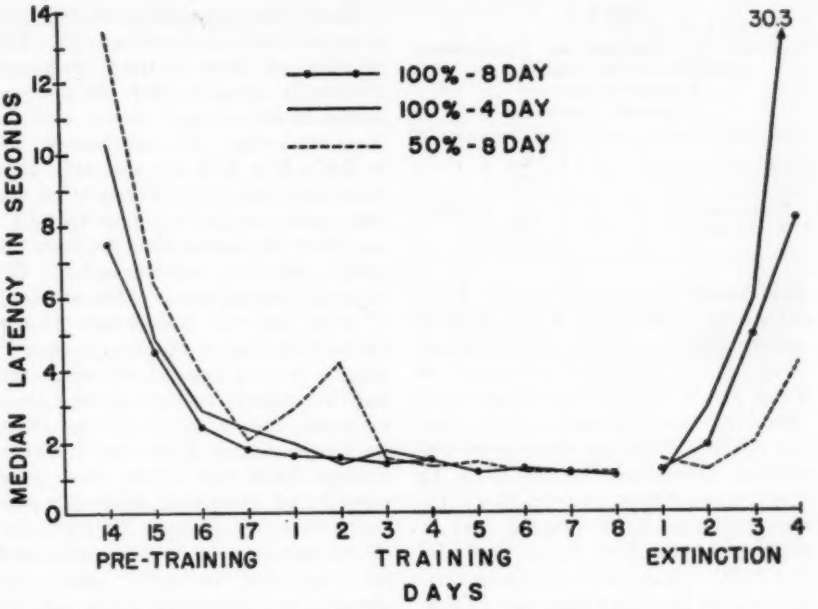

FIG. 2. Latencies of pooled experimental and control groups during runway pretraining and training and for the control group during extinction

the experimental groups. The basic measure in the preliminary training and acquisition for each *S* was the median latency on the daily runway trials. Since only chance differences separated the three reinforcement groups in pretraining (Fig. 2) we can conclude that the groups were initially equivalent. The application of the differential reinforcement conditions in acquisition led to a pronounced retardation in the performance of the partially reinforced *S*s on the first two days of training. In this period the latencies of Groups 100-4 and 100-8 were significantly smaller ($p < .01$) as determined by an analysis of variance and t tests, and there was only a chance difference between the two 100% groups. With continued training the differences diminished so that Group 100-8 and Group 50 were indistinguishable on the last four days of runway training. At termination of runway training all the groups were responding with equal facility.

The runway latencies served as response measures in evaluating the extinction performance of the control groups. To meet the assumptions for analysis of variance the raw scores

TABLE 1

ANALYSIS OF VARIANCE OF TRANSFORMED LATENCIES IN THE OVER-ALL EXTINCTION PERIOD FOR THE CONTROL GROUPS

Source of Variation	*df*	Mean Square	*F*
Groups	2	.415	2.05
Days	3	1.288	27.40
Groups × days	6	.162	3.45
Composite error	48	.086	
Intersubject	12	.202	4.30
Intrasubject	36	.047	

TABLE 2

ANALYSIS OF VARIANCE OF TRANSFORMED LATENCIES ON THE LAST DAY OF EXTINCTION FOR THE CONTROL GROUPS

Source of Variation	*df*	Mean Square	*F*
Between groups	2	.365	4.93
Within groups	12	.074	

were transformed into common logarithms (**6**). The results of this repeated measurements analysis (**5**) of the four days of extinction are presented in Table 1. While the over-all means of the three reinforcement groups were not reliably different, there were significant differences in the trials ($p < .01$) and differential extinction rates were indicated by the significance of the groups and days interaction ($.05 > p > .01$). A simple analysis of variance of the last extinction day (Table 2), where the groups diverged maximally, indicated that the difference between Groups 100-4 and 50 was very significant ($p < .01$). The difference between Groups 100-8 and 50 ($p = .075$) and between Groups 100-4 and 100-8 ($p = .075$) were in the expected direction but only suggestive in magnitude.[2] The superior resistance to extinction of the partially reinforced *Ss* and the greater resistance of the continuous group with the greater number of primary reinforcements are in accord with other investigations (**3, 4**).

The experimental *Ss* were confronted in retraining by a three-choice situation: they could (*a*) respond to the correct side alley, (*b*) fixate on the formerly rewarded runway, or (*c*) enter the incorrect side alley. Figure 3 shows the acquisition of the new black-white discrimination habit. The analysis of these correct responses (Table 3) revealed that the discrepancies in the groups' means were at the borderline of significance ($F = 3.17$; $F = 3.23$ for $p = .05$), that there were marked differences on the successive days of training ($p < .01$), and that the interaction between the groups and days was negligible. Because of the magnitude of the obtained *F* ratio and the consistency of the curves from day to day and sample to sample it was decided to reject the null hypothesis and compute *t* tests between the groups.[3] Since there were only chance differences between Groups 100-4 and 100-8, these were pooled and compared with the partially reinforced group. This test disclosed that the continuously rewarded *Ss* responded correctly more frequently, the difference being reliable between the .05 and .01 levels of confidence.

The fixation errors committed by

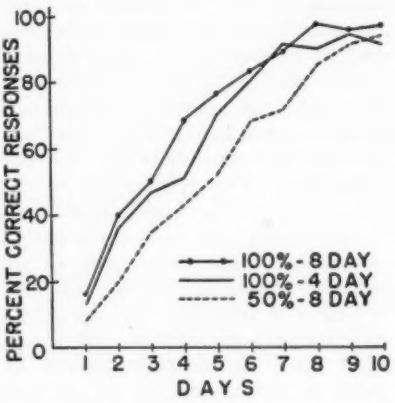

FIG. 3. Percentage of correct responses made by the experimental groups on successive days of retraining in the black-white discrimination problem

[2] One tail of the *t* distribution was employed in the determination of the probability level in these three comparisons since the order was predicted prior to the experiment.

[3] This *t* test was done by *Ss*, combining days.

the experimental groups (Fig. 4) were treated by a simple analysis of variance technique. To attain variance homogeneity it was necessary to convert the total fixation errors into logarithms. The resulting analysis of variance (Table 4) and subsequent t tests revealed that in each instance the 100%-reward group perseverated less than the 50%-reward group ($p <$ .01) and that there was no reliable difference between the two continuously rewarded groups.

In discrimination errors there were negligible differences in the over-all means of the three groups. There were trends in the data for the 100%-reinforcement *Ss* to make a greater number of incorrect side alley entries than the partially reinforced *Ss* in the first five days of retraining and for the opposite to occur in the last half of retraining. These trends, however, did not meet the criterion of statistical significance.

We may conclude from the examination of the retraining data that: (*a*) The *Ss* who learned the initial runway response under the continuous reinforcement condition made more correct responses in the mastery of the new discrimination response. (*b*) The partially reinforced *Ss* tended to fixate more on a functionally outmoded form of action. (*c*) In acquiring the new instrumental sequence the groups erred equally in terms of their selection of the incorrect side alley.

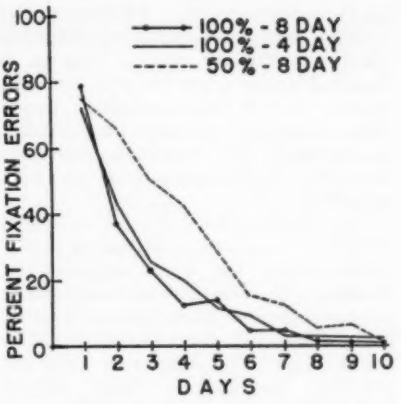

FIG. 4. Percentage of fixation errors made by the experimental groups on successive days of retraining on the black-white discrimination problem

DISCUSSION

During the control condition, where the conventional extinction technique was employed, the partially reinforced *Ss* displayed greater resistance to response disruption than the continuously rewarded *Ss*. This outcome is in accord with earlier investigations (4). Likewise the intermittently rewarded *Ss*, undergoing the experimental treatment of retraining, showed a pronounced tendency to fixate on the runway alley. The findings in the retraining phase are in agreement with the pioneer investigation of Brunswik (1) and the more recent

TABLE 3

ANALYSIS OF VARIANCE OF CORRECT RESPONSES IN THE OVER-ALL RETRAINING PERIOD FOR THE EXPERIMENTAL GROUPS

Source of Variation	*df*	Mean Square	*F*
Groups	2	15.88	3.17
Days	9	91.04	104.64
Groups × days	18	.67	
Composite error	400	1.28	
Intersubject	40	5.01	5.76
Intrasubject	360	.87	

TABLE 4

ANALYSIS OF VARIANCE OF TRANSFORMED FIXATION ERRORS IN THE OVER-ALL RETRAINING PERIOD OF THE EXPERIMENTAL GROUPS

Source of Variation	*df*	Mean Square	*F*
Between groups	2	.205	7.32
Within groups	40	.028	

study by Wilcoxon (9). Thus the results of this investigation lead to the following general conclusion: when a response is acquired under a partial reinforcement regimen it will resist extinction longer than a response conditioned by continuous reinforcement whether extinction is assessed in the customary fashion or by a retraining test.

One explanation for the enhanced resistance to extinction following partial reinforcement has been suggested by Sheffield (8). The runway response is conditioned to an afferent stimulus complex which includes the perseverative traces from the previous trial. For the partially rewarded *Ss* under massed training the response is conditioned to the aftereffects of both reinforcement and nonreinforcement, while the continuously rewarded *Ss*' traces are those arising solely from reinforcement. Accordingly, in the transition from training to extinction the stimulus complex for the former group undergoes less generalization decrement and extinction proceeds more slowly. In the case of distributed training the aftereffects diminish with the passage of time making the afferent stimulus complex more identical for the partially and continuously reinforced *Ss* and reducing the effectiveness of partial reinforcement in extinction. In the present design the perseverative trace effects were maximized by the short intertrial interval which precluded the dissipation of the aftereffects.

Summary

Fifty-eight rats were trained to traverse a runway under three conditions of reinforcement—two levels of 100% reward and 50% reward. In the control treatment *Ss* from each reinforcement condition were extinguished by omitting reinforcement. In the experimental treatment *Ss* could achieve reinforcement during extinction by the solution of a black-white discrimination problem. The partially reinforced control group showed the maximum resistance to extinction in the regular extinction procedure. Likewise the experimental 50%-reward *Ss* fixated more on an outmoded response and scored fewer correct responses in the mastery of a new instrumental sequence. It was concluded that when a response is acquired under a partial reinforcement regimen, it will resist extinction longer than a response conditioned by continuous reinforcement whether extinction is assessed in the customary fashion or by a retraining test.

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PERCEPTION OF BODY POSITION IN THE ABSENCE OF VISUAL CUES

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A number of previous studies have investigated variables affecting the perception of the postural vertical. Most of these studies, however, have been concerned with the perception of the postural vertical with variations in the visual field. Moreover, much of the research has centered on the question of whether postural or visual factors are of primary importance in the maintenance of bodily equilibrium. A critical evaluation of such studies has been presented by Gibson and Mowrer (**2**) and more recently by Gibson (**3**).

There have been, however, only a few studies (e.g., **4, 5, 6**) which have attempted to explore systematically the effects of certain conditions on the perception of bodily position in the absence of visual cues. The present paper describes two experiments which investigated the effects of a number of such conditions on accuracy of adjustment to an upright position in the absence of a visual frame of reference. The primary variables manipulated under these conditions were speed, magnitude, and direction of the original displacement from the postural vertical. Also investigated was the influence of fixed versus free head position on accuracy of adjustment.

[1] Lackland Air Force Base, San Antonio, Texas. The opinions or conclusions contained in this article are those of the author. They are not to be construed as necessarily reflecting the views or indorsement of the Department of the Air Force.

Experiment I

Apparatus and Procedure

The apparatus consisted of a tilting-chair arrangement, which can be displaced to one side or the other by either *E* or *S*. The test apparatus is shown in Fig. 1. The chair can be displaced to a maximum arc of 25° on either side of the vertical position. The speed of displacement is controlled by *E* and can be varied at intervals of from 3° to 7° of movement per second. An optional headrest can be lowered to immobilize *S*'s head. The *S* is strapped into the chair with a shoulder harness and belt arrangement and his feet are positioned on the appropriate footrest.

The *S* was placed in the experimental chair and given the following instructions: "This is an experiment to see how well you can adjust yourself to an upright position after you are placed in a tilted position. I will first tilt you to some inclined position and when I instruct you to do so, you are to return the chair as nearly as you can to the position in which you are now. You can move the chair by pressing these buttons in the arm rests. Push the right button to move to the right, and the left button to move to the left (demonstrated). When you are satisfied that you are in an upright position, say 'level.' Following this you will be placed in another tilted position and again you will be asked to return to an upright position. Each time try to come as close as you can to a perfectly upright position." The *S* was blindfolded with fitted, black opaque goggles during the experiment. In this first experiment *S*'s head position was *not* held fixed. None of the trials involved knowledge of results; that is, *S* was not "righted" to the level position nor given any indication of his error.

Three displacement speeds of 4°, 5°, and 6° per second, and three amounts of tilt—15°, 20°, and 25°—were used. All combinations of speeds and displacement angles were used, giving nine combinations in all. Each *S*'s time in the tilted position was held constant at 5 sec. Ninety basic trainee airmen were utilized in this experiment, independent groups of ten randomly assigned to each degree of tilt-speed condition. Each *S* received 12 trials in a single sitting. The direction of tilt (right or left) varied from trial to trial in the following randomly determined

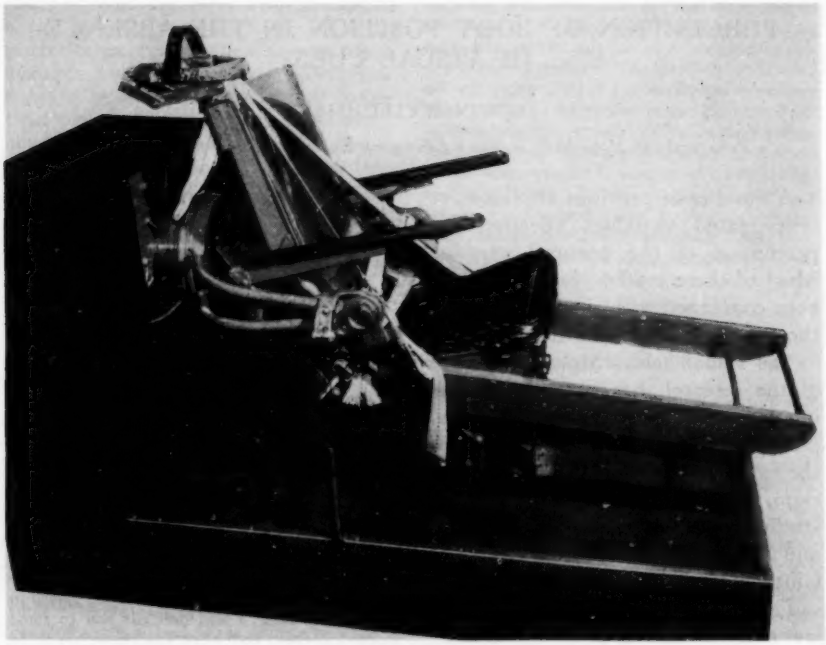

FIG. 1. The tilting-chair apparatus

sequence: RLRRLLRLLRLR. This same sequence was used for each *S* and in each degree of tilt-speed combination.

Since for any *S* the chair moved with the same speed when it was being returned by *S* as when it was displaced by *E*, a separate control group of 90 *S*s was utilized in which the speed of return and speed of displacement were randomized for each trial. This control group thus received unequal speeds from trial to trial and from displacement to return within each trial. This group was used to check the possibility that *S* was "timing" himself back to the true vertical position rather than responding to postural cues. The direction of tilt from trial to trial for the 12 trials per *S* followed the same sequence as that in the main experiment. The sequences of displacement and return (*S*'s adjustment) speeds for each trial in this group were as follows:

	Degrees per Second
Speed of displacement (By *E*)	4 5 4 6 5 5 6 4 6 5 4 6
Speed of return (By *S*)	5 4 4 5 6 5 5 6 4 6 5 4

Effects of speed and magnitude of displacement.—Table 1 summarizes the results obtained when average error is used as the measure of precision of adjustment.[2] The results in this table are in terms of mean degree

[2] *Average error*, as used in the present study, is to be distinguished from *variable error*. The latter term has frequently been used as a measure of precision, especially in investigations of a "psychophysical" nature. Variable error represents "precision" around the mean (e.g., constant error) of a series of judgments. Primary interest in the present study, however, is in precision with respect to a standard, the "true" upright position (0°). In this sense, the term average error, representing mean variation from this standard, appears to be the more appropriate measure of precision. *Constant error* is also of interest in that this gives an indication of the direction of the obtained error (the tendency to overestimate or underestimate) and the magnitude of its discrepancy from the "true" position.

TABLE 1

MEAN AVERAGE ERROR (DEGREES) OF ADJUSTMENT FOR DIFFERENT SPEEDS AND AMOUNTS OF DISPLACEMENT

Degrees of Body Displacement	Speed of Displacement $N = 90$				Random Speeds $N = 90$
	Degrees per Second			Mean	Mean
	4°	5°	6°		
25°	3.0	2.6	2.1	2.6	2.5
20°	2.0	2.0	1.6	1.9	2.1
15°	1.6	1.4	1.3	1.5	1.6
Mean	2.2	2.0	1.7	2.0	2.1

deviations from 0° (the upright position). Each cell mean is based on 12 adjustments made by 10 *S*s, or 120 judgments.

It can be seen that there is a greater average error as speed of displacement decreases and as magnitude of displacement increases. The F ratios were 4.4 ($.05 > p > .01$) for speed and 17.5 ($p < .01$) for magnitude. The interaction between these main effects (speed and magnitude of displacement) was not significant.

The last column in Table 1 compares these results with those obtained from the control group which received the random speed conditions. The close correspondence between the mean average error of the control group (random speeds) and the experimental group is apparent (within-group variance larger than variance between groups). Apparently, *S*s in the experiment were responding to postural cues rather than to "time" cues. The differences between displacement angles were also significant for the random speed group ($F = 12.1$, $p < .01$).

Table 2 summarizes the mean constant errors made by *S*s under each condition. In all cases the mean constant error was found to be in the direction of initial displacement. That is, *S*s tended to "undershoot" rather than "overshoot" when adjusting themselves to the upright position. These data also show an increasing constant error in the direction of initial displacement as magnitude of displacement increases ($F = 10.7$, $p < .01$). Differences in constant error as a function of displacement speed do not reach the .05 level of significance ($F = 2.9$). With respect to constant errors, the correspondence between our random-speed control group and the experimental group again is evident in the last two columns of Table 2.

Effects of direction of displacement.—Another finding was the significant difference ($t = 6.2$, $p < .01$) in mean average errors between the six trials in which *S*s were displaced to the right and the six trials in which they were displaced to the left. For the trials in which *S* was displaced to the right, $M = 2.23$, $\sigma = 1.31$. For displacements to the left, $M = 1.67$, $\sigma = 1.15$. Moreover, these differences were found for each of our independent groups of ten *S*s within each speed and degree of displacement combination. The correlation between average errors for

TABLE 2

MEAN CONSTANT ERRORS (DEGREES) IN DIRECTION OF INITIAL DISPLACEMENT FOR DIFFERENT SPEEDS AND AMOUNTS OF DISPLACEMENT

Degrees of Body Displacement	Speed of Displacement $N = 90$				Random Speeds $N = 90$
	Degrees per Second			Mean	Mean
	4°	5°	6°		
25°	2.5	2.4	1.7	2.2	2.2
20°	1.4	1.7	1.4	1.5	1.8
15°	1.4	1.2	.9	1.2	.9
Mean	1.8	1.8	1.3	1.6	1.6

right and left displacement trials was .76.

The explanation for the finding that displacement to the right is a more difficult condition than displacement to the left is not immediately apparent. Nothing in the apparatus could be found to account for these results. A question was raised concerning the relationship between "handedness" and this phenomenon. Since most of the *Ss* in the study were right-handed, two additional independent groups were given the 12 experimental trials. One group of 30 *Ss* contained all left-handed *Ss* and the other group included all right-handed *Ss*. The results of this additional experiment showed no significant differences between the two groups in mean average error for the 12 trials ($t = .18$, $p > .05$), for the six "right" trials ($t = .12$, $p > .05$), or for the six "left" trials ($t = .41$, $p > .05$). Moreover, within the right-handed group, greater mean average error again resulted in "right" trials than in "left" trials ($t = 3.02$, $p < .01$), as was the case with the left-handed group ($t = 4.31$, $p < .01$). The hypothesis that the direction of displacement (right or left) resulting in greater average error is a function of *Ss*' "handedness" is rejected.

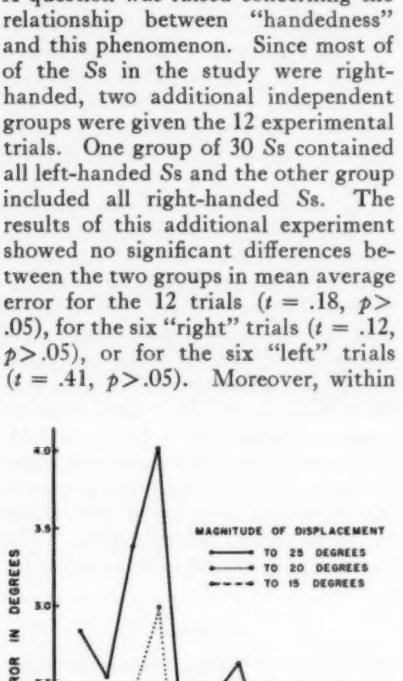

FIG. 2. Performance curves for three magnitudes of displacement

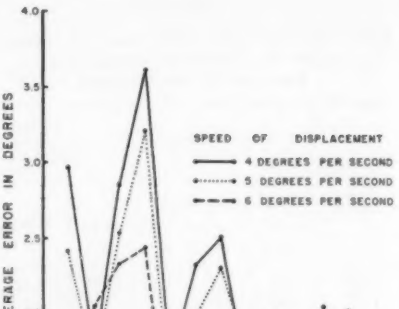

FIG. 3. Performance curves for three displacement speeds

Effects at different stages of practice.—Figure 2 presents performance curves (using average error as the measure of precision) for the 12 experimental trials for each of the three amounts of displacement. Figure 3 presents similar curves for the three speed conditions. It will be recalled that none of the trials involved giving *S* knowledge of results.

It can be seen that the curves in Fig. 2 are generally parallel and that magnitude of displacement appears to be an important determiner of difficulty at various stages of practice. Similar results are found in Fig. 3,

although the results with respect to speed are not as clear-cut at various levels of practice.

Although there seems to be some improvement with practice, the degree of learning occurring during these 12 trials cannot be readily inferred from these curves, owing to the curious peaks which occur at certain stages. The peak occurring through Trials 3 and 4, for example, is evident in all our independent groups under all conditions. A closer examination of these trials indicates that the peaks generally occur during trials in which *S* is displaced to the right. We have seen previously that displacement to the right results in greater average error. Moreover, Trials 3 and 4 are the only places in the trial sequence in which two "right" trials occur successively. The inference might be made that there is some summation effect resulting from successive presentations of this more difficult condition.

Sequence effects.—In order to check this hypothesis further, an additional group of 90 *S*s was run under identical conditions with the main experimental group. The only change instituted was an inversion of the right-left displacement sequence received. The sequence for this group was thus: LRLLRRLRRLRL. Figure 4 compares the performance curves obtained for this additional group with that obtained for the main experimental group.

It can be seen from Fig. 4 that this peak at Trial 4 does not occur for the group with the inverted sequence. Moreover, the peaks do occur for this latter group when the two "rights" are given successively later in the sequence, although these peaks are not as marked. The difference between the mean average error made by the two groups was significant beyond the .01 level in favor of less average error made by the inverted-sequence group. As with the main experimental group, there was significantly greater average error ($p < .01$) for "right" trials than for "left" trials within the inverse-sequence group. Thus, it appears that sequence (with respect to direction displacement) is an important contributor to precision of adjustment. It also appears that the difference in the two groups (differing in sequence) is primarily explainable at the early stages of performance. The introduction of two difficult trials ("right" displacements) in a row at an early stage of practice seems more detrimental to over-all performance than the introduction of such trials at later stages.

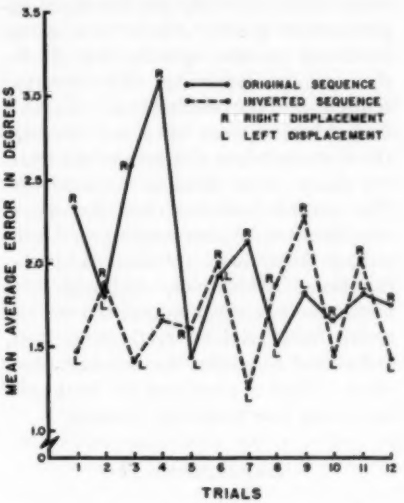

FIG. 4. Performance curves for original and inverted sequences

Consistency of individual performance.—The last problem to be considered under Exp. I is that of the consistency of individual performance in precision of adjustment to an upright position. Corrected split-half reliability coefficients (based on the average error for the six odd versus six

even trials) were .93 for the main experimental group, .88 for the group receiving random speeds, and .91 for the group receiving the inverted sequence. Correlations of .72, .67, and .61 also were obtained between the first six trials and second six trials for these three groups, respectively. The results indicate that the scores obtained are reliable measures of individual differences in this particular function. Moreover, although the mean average error fluctuated for the group from trial to trial (Fig. 2–4), individual Ss tended to maintain their same relative positions in both the early and late stages of practice.

Experiment II

The results of Exp. I were obtained under conditions in which S's head position was not held fixed. Experiment II is essentially an investigation of the same variables under conditions in which S's head was held fixed in an upright position, presumably reducing certain of the labyrinthine and kinesthetic cues available in the first study. A comparison also was made of the over-all effects of both free and fixed head position on precision of adjustment.

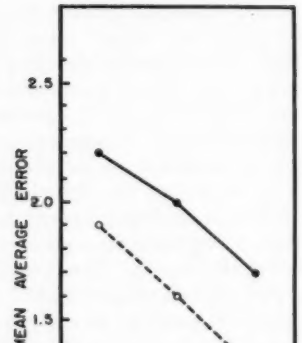

Fig. 5. Average error of adjustment for different displacement speeds with and without fixed head position

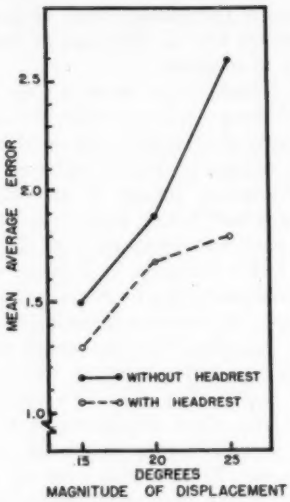

Fig. 6. Average error of adjustment for different displacement magnitudes with and without fixed head position

Apparatus and Procedure

The apparatus consisted of the same tilting-chair arrangement described under Exp. I, except that S was fitted with the headrest. The headrest which was lowered over S's head was padded with foam rubber and adjustable to S's height and head size. Head size was controlled by a knob-screw adjustment which tightened the headrest ring around the head. Each S's head was held so that its medial plane approximated the gravitational vertical.

The instructions given S and all other procedures and conditions were identical with those described under Exp. I. Another sample of 90 Ss drawn from the same population of basic trainee airmen was utilized in the present study.

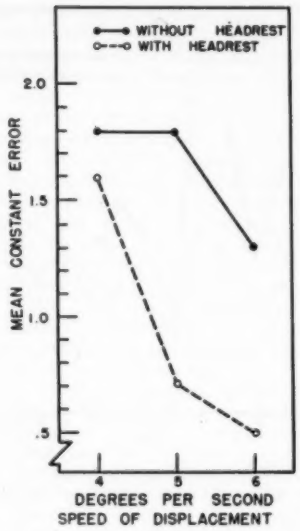

FIG. 7. Constant error of adjustment (in the direction of initial displacement) for different displacement speeds with and without fixed head position

Results

Figure 5 presents the mean average error for the three displacement speeds. Figure 6 presents the mean average error for the three displacement angles. For comparison purposes, the curves obtained from the group previously tested without the headrest are also presented in each figure

In Fig. 5 it can be seen that there is smaller average error as speed of displacement increases when the head is held fixed ($F = 8.2$, $p < .01$). This result confirms the earlier results with *Ss* whose head position was not held fixed. It also can be seen in Fig. 6 that increasing average error results as magnitude of displacement increases among *Ss* whose head was held fixed ($F = 8.6$, $p < .01$), as was found with *Ss* whose head position was not held fixed. These curves also show that when the head is held fixed, *Ss* achieve smaller average error (greater precision) in their adjustments to the upright position ($F = 8.8$, $p < .01$).

In both sets of curves the functions generally appear parallel within the limits of the speeds and magnitudes of displacements investigated. A possible exception is found in the case of the largest displacement angle (Fig. 6). It appears that at the upper range of displacement angles investigated, magnitude of displacement makes more of a difference for *Ss* whose head position was not fixed than for *Ss* with fixed head position.

Figures 7 and 8 present the results for mean constant errors under the various conditions. As in the previous study, constant errors were found to be consistently in the direction of initial displacement; that is, *Ss* tended to "undershoot" rather than "over-

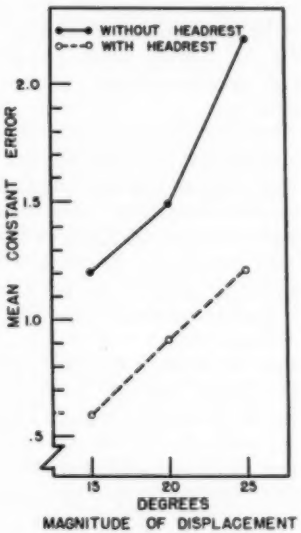

FIG. 8. Constant error of adjustment (in the direction of initial displacement) for different displacement magnitudes with and without fixed head position

shoot" the "true" upright position. The amount of constant error was found to decrease as speed of displacement increased ($F = 15.5$, $p < .01$) and to increase as magnitude of displacement increased ($F = 5.0$, $p < .01$). In the previous study (group with free head position) differences in constant error between displacement magnitudes were also significant beyond the .01 level but differences in constant error between displacement speeds did not reach the .05 level of significance. In Fig. 7 it can be seen that this later result was primarily due to the insignificant difference in constant error between the slowest displacement speeds among *Ss* in this group. Thus, it appears that a drop in constant error occurs at a slower displacement speed for *Ss* whose head position is fixed than for *Ss* whose head position is not fixed.

It can also be seen that constant error is significantly less among *Ss* whose head position is held fixed than among *Ss* whose head position is allowed to move freely ($F = 23.0$, $p < .01$).

In Exp. I it was found that direction of displacement was a significant variable contributing to precision of adjustment. Similar results were obtained in the present study. Thus, even when *S*'s head position was fixed, greater average error resulted during trials in which *S* was displaced to the right ($t = 2.5$, $p < .02$).

Figure 9 presents the performance curves (using average error as the measure of precision) for the 12 experimental trials of the 90 *Ss* with the headrest and for the 90 *Ss* without the headrest. It can be seen that the differences between the two curves are generally greater in the earlier stages of practice. The curious peak occurring at Trial 4 was partially explained in Exp. I on the basis of sequence

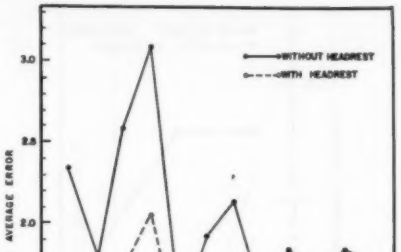

FIG. 9. Performance at various stages of practice with and without fixed head position

effects and the presence of two more difficult trials (right displacements) in a row at this point. Although the degree of learning cannot be readily inferred from these curves, it is apparent that at various stages of practice those *Ss* whose head position was fixed tended to make more accurate adjustments to the upright position.

Consistency of individual performance in precision of adjustment to an upright position with the head held fixed was found to be high. The corrected odd-even trial reliability coefficient was .91, while the correlation between the first and last six experimental trials was found to be .70. These compare favorably with similar coefficients obtained from the group whose head position was not fixed (.93 and .72, respectively).

DISCUSSION

The findings in both experiments that with increasing magnitude of displacement there is (*a*) increasing average error of adjustment, and (*b*) increasing constant error in the direction of initial displacement, substantiate earlier findings by Mann and Passey (5). The correspondence

of these results seems especially significant since the experimental procedure and experimental apparatus as well as the sampling procedure of the present studies differed from the earlier investigation. Mann and Passey used only three *Ss* (sophisticated in this research area), each of whom made 480 judgments in 20 experimental sessions. The present experiments utilized 90 naive *Ss*, each of whom made 12 judgments in a single sitting. Moreover, in the present studies, *S* was not told the correct position after each trial. In the Mann and Passey study, *S* was righted to the level position, stopped and told he was now level after each trial. While the earlier study varied magnitude of displacement over a wide range (5° to 55°) at 10° step intervals, the present experiments varied magnitude at smaller step intervals (5°) within a narrower range (15° to 25°). Thus, the present results indicate that the precision with which adjustments to the postural vertical can be made is sensitive to even smaller differences in displacement magnitudes than was possible to infer from the Mann and Passey data.

It should also be noted that precision of adjustment is influenced by very small differences in speed of displacement (as little as 1° per second). However, the conclusions regarding speed as a factor are limited by the restricted range of speeds investigated. The upper and lower limits of speed as a factor have not been determined in the present study. The results with respect to speed are similar to an early observation by Burtt (1) that rapid inclination from an upright position results in detection of tilt for smaller magnitudes than when less rapid inclination is used.

In the present experiments, the amount of time *S* was held in the displaced position was held constant, while speed of displacement was varied. In the Mann and Passey study, time in the displaced position was varied while speed of displacement was presumably held constant. They found that the larger the exposure in the displaced position, the greater the average error. Our finding that slower speed of displacement resulted in larger average error may be a reflection of the same phenomenon, since the time *S* is kept in a position other than upright is involved in both variables. It seems useful at present, however, to conceive of speed of displacement and time of exposure in the displaced position as separate variables for future experimental verification. Whether it is the gravitational forces during *S*'s displacement or the overall time delay before *S*'s adjustment which contributes most to precision of adjustment is yet an unanswered question. Latency of reinforcement within trials does not seem to be an adequate explanation, since in the present study *S* was not corrected after each trial. Later studies are also investigating this variable.

The finding that greater precision resulted when *S*'s head was held fixed was not entirely anticipated. Apparently the additional cues which *S* has available in the situation where his head position is not fixed are largely irrelevant and misleading. For example, among certain *Ss* whose head position was not fixed, it could often be noted that as *S* approached the upright position he would move his head a few degrees and assume that his whole body was now in the upright position. Greater precision results when the head is held in the medial plane, thus providing more dependable cues of orientation with respect to deviations from the "true" upright position. It should also be pointed out that restraining the head undoubtedly provides additional *tactual* cues not present in the "unfixed" head situation. Future studies should be aimed at evaluating the relative importance of these and other cues. The present study makes no attempt to identify with any degree of assurance the specific sources of sensory stimulation contributing to precision of bodily adjustment.

It was also noted that *Ss* whose head position was fixed tended to show a decrease in constant error of adjustment at a slower speed of displacement than did *Ss* whose head position was not fixed. In the case of the latter group, the constant errors showed no decrease from displacement speeds of 4° per second to 5° per second. However, among *Ss* whose head position was fixed, significant decreases in constant errors resulted between these two speeds (Fig. 7). These results, together with the tendency for a sharper rise in constant error at greater magnitudes of displacement for the group whose head position was not fixed (Fig. 8) suggest that there might be a differential effect of free versus fixed head position at different ends of the speed and magnitude of displacement scales. Thus, it may be that allowing the head to remain unfixed makes more of a difference at greater displacement magnitudes and at slower displacement speeds. As the more difficult conditions are introduced (slower and greater displacements) it may become increasingly important that *S*'s head position remain fixed in the medial plane with respect to the rest of his body in order for him to be able to readjust optimally to the "true" upright position. The limited number of displacement speeds and magnitudes investigated afforded me opportunity to explore this possibility further in the present study.

No satisfactory explanation is currently available for the significant results found for direction of displacement. The influence of "handedness," sequence and apparatus variables as factors in these findings has tentatively been rejected by

the present study. Since this directional difference was found when the head was held fixed as well as when the head was not fixed, the irrelevant cues apparently used by *S* in the latter situation cannot satisfactorily account for this phenomenon. This finding of a significant difference between displacement directions does not confirm an earlier finding by Passey and Guedry (6), who found no significant difference between displacement directions. However, these investigators used eight *Ss* sophisticated in this research area, and eight *Ss* who were in pilot training (although these latter *Ss* had no flying experience). Moreover, *Ss* were allowed to practice with the apparatus, with reference to visual objects, before using the goggles, and adjustments were made by means of a control stick. These aspects of their procedure may have afforded *S* some additional cues not available in the present experiment. The apparatus used in their study was also markedly different from that used in the present study. These discrepancies between procedures and results indicate the need for further study to investigate these findings more properly.

The importance of sequence variables has been pointed up to the extent that two of the more difficult trials (right), introduced early in practice, contributed more error than the introduction of these trials later in practice.

Consistency of performance found for individual *Ss* (whether the head was held fixed or not) suggests that some stable ability (or abilities) is being sampled. This points up the possibility of a modified form of the apparatus for use as an experimental psychomotor test. In the job of aircraft pilot, for example, the ability to respond and adjust to postural changes and to maintain orientation with respect to the upright position seems to be especially important, particularly under conditions of reduced visibility.

Summary

Two experiments investigated the influence of certain factors on accuracy of adjustment to an upright position in the absence of a visual frame of reference. The *Ss* were subjected to displacement magnitudes of 15°, 20°, and 25° in a lateral plane, and displacement speeds of 4°, 5°, and 6° per second in a tilting-chair arrangement. Direction of tilt varied from trial to trial in a randomly determined sequence. In Exp. I *S*'s head position was not held fixed, while in Exp. II *S*'s head position was fixed so that its medial plane approximated the gravitational vertical. The results indicate:

1. Greater precision of adjustment to the upright position results when the head position is fixed than when the head position is not fixed.
2. Similarly, smaller constant error of adjustment results when the head position is held fixed, although constant error is in the direction of initial displacement under both conditions.
3. When head position is fixed as well as when head position is not fixed, greater precision of adjustment results as speed of displacement increases, and as magnitude of displacement decreases.
4. Under both conditions, greater precision of adjustment results when direction of displacement is to the left than when direction of displacement is to the right.
5. Sequence of trials with respect to direction of initial displacement seems to be an important variable in over-all error.
6. Magnitude and speed of displacement are important determiners of precision of adjustment at various stages of practice.
7. Individual *Ss* show a high degree of consistency in precision of adjustment at various stages of practice.

The findings are related to previous work and questions raised by the present study are discussed.

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A SEARCH FOR SUBTHRESHOLD CONDITIONING AT FOUR DIFFERENT AUDITORY FREQUENCIES[1]

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The problem of whether an energy value that is below a psychophysical threshold can be a stimulus was first brought under experimental attack by Suslowa in 1863 (**22**). Since then numerous investigations have been reported which indicate the presence of such a phenomenon. The problem is of interest because it indicates that there may be a "physiological threshold" below the psychophysical threshold which can mediate a response to an energy value. This paper is concerned with only a part of the general problem, namely, whether a frequency within the auditory range and at an intensity below the absolute threshold can become a conditioned stimulus. The first study on this problem with the auditory modality was reported by Dunlap (**5**) in 1904. Baker (**1**), in 1937, reported results which supported Dunlap's observations. He employed two different frequencies each at an intensity below the absolute threshold. His *Ss* were required to guess between a dash-dot and a dot-dash pattern. All *Ss* could make a correct judgment with a better than chance frequency.

In 1939 Baker (**2**) reported another study in which he found that the pupillary light reflex could be conditioned to a tone below the absolute threshold. Using the below-threshold tone as the CS and a change in illumination as the UCS, he found that (*a*) a CR to the subthreshold tone was established in two trials and reached its final form on the third trial, (*b*) responses conditioned to subthreshold sounds were more specific than responses conditioned to suprathreshold sounds (i.e., they did not generalize as rapidly), and (*c*) they were much more stable than suprathreshold conditioned responses (i.e., there was no evidence of extinction after a 6-mo. period). In a repeat study, Metzner and Baker (**16**) observed the same results. However, in 1940 Wedel, Taylor, and Skolnick (**23**) repeated the study with both a pure tone and a noise pattern, each subthreshold, and found no evidence of conditioning in any of the *Ss* employed.

Davis (**4**) has recently reported an investigation which seems to indicate that electromyographic potentials can be influenced by a tone near the absolute threshold. A 1000-cps tone was presented to *Ss* while potentials were being recorded from several different muscle groups. Changes in the electromyogram were observed to intensity values that *Ss* did not report hearing. Davis did not relate his results to the problem under consideration here, but it appears that his data offer evidence that "subthreshold stimulation" can occur under these conditions.

The results of the previous studies on conditioning to below threshold sounds are inconclusive on three points: (*a*) the reflex to be conditioned was improperly chosen; (*b*) there is inadequate specification of the

[1] This paper forms the main body of a Ph.D. thesis presented to the Department of Psychology at the University of California at Los Angeles. The writer is indebted to Dr. George E. Mount whose advice and help made this study possible. An abstract of this paper was presented at the 1952 meetings of the Western Psychological Association.

absolute threshold; and (*c*) other frequencies might have remitted in conditioning.

All the previous investigators used the pupillary light reflex, and there exists doubt that this reflex can be conditioned at the suprathreshold level. While Cason (**3**) and Hudgins (**13**) have reported that the pupillary light reflex can be conditioned, there have been several unsuccessful attempts to repeat their observations (**18, 19, 20**). Recently, Hilgard *et al.* (**7, 8**) have conducted two separate investigations of pupillary conditioning, with several different experimental procedures. Their results lead them to a negative conclusion regarding the possibility of pupillary conditioning. It therefore appears that the investigators who employed this reflex in an attempt to demonstrate subthreshold conditioning were working with an unknown quantity. It seems that a more adequate test for conditioning to below-threshold energy values should employ a reflex for which there exists no doubt as to whether it can be conditioned at the suprathreshold level. For this reason the galvanic skin response (GSR) was used in the present study. It has the advantages that (*a*) it is a reflex which we know can be conditioned readily to suprathreshold stimuli, and (*b*) it can be accurately recorded.

The procedure employed for the specification of the absolute threshold is of crucial importance in this problem. Baker was not clear as to the intensity of the tone he used as the CS in his study. He merely stated that it was two audiometer units below the average threshold value. He gave no indication of the magnitude of his audiometer units. Metzner and Baker employed the same procedure. For purposes of this problem the absolute threshold is defined in the following manner. Instead of being specified as a single point or a single intensity level, it will be specified as a range between two intensity levels. These two intensity levels are (*a*) the lowest intensity level which *S* can consistently hear, and (*b*) the highest intensity level that *S* did not report hearing in five successive trials. An intensity at, or above, the first level is considered suprathreshold, and any intensity at, or below, the second level is considered as being subthreshold. This procedure not only has the advantage of establishing the subthreshold level at a level to which *S* did not overtly respond, but also indicates the range between the suprathreshold and subthreshold levels which is in turn a measure of the reliability of *S*.

As the human auditory mechanism is not equally sensitive to all frequencies across the sound spectrum, it may be that the frequency value of the sound energy used is an important variable. Subthreshold conditioning may occur to frequencies at one part of the sound spectrum and not at the other. Recognizing that this may be the case the low frequency and high frequency sections of the curve should be explored as well as the middle frequencies. In accordance with this reasoning, the following frequencies were used in the present study: (*a*) pure tones at 200, 2000, and 13,000 cps, and (*b*) a thermal noise containing frequency components from zero to 20,000 cps as modified by the transducer.

Procedure

Instrumentation.—The GSR apparatus consisted essentially of a Wheatstone bridge coupled with a DC amplifier. The output of the amplifier was connected to an Esterline-Angus Graphic Ammeter (Model AW). The electrodes consisted of ¾-in. zinc plates set in 1-in. plastic cups and were placed on the palms of *S*'s hands. The *S* lay prone on a canvas cot.

The pure tones were generated by a Hewlett-Packard Low Frequency Oscillator (Model 202b), and the noise by a Grason Stadler Noise Generator (Model 455-A). Attenuation in 1-db units was accomplished by means of a Hewlett-Packard Attenuator Set (Model 350A). The sound transducer was a hearing-aid phone of the crystal type produced by the Brush Co. To reduce the transient disturbance associated with turning the sound on and off the sound was passed through a potentiometer which was turned by a small DC motor. This minimized the occurrence of a transient disturbance even though the sound appeared to be going on and off instantaneously to *S*.

The UCS was a condenser discharge DC shock pulsating 60 times per second and applied to the right ankle of *S*. It was produced by a Goodwin Shock Stimulator (Model No. 3). The duration was ½ sec. Its magnitude was 25 v. above *S*'s shock threshold.

The presentation and recording of the CS and UCS were controlled automatically by means of a rotary switch.

Threshold specification.—Threshold determinations, as well as the experiment proper, were made in a room in which the average noise level appeared to be below threshold. The only noises that could be detected by listening were those made by breathing and heart beat, which were clearly audible.

A free-field procedure was used. In order to maintain *S*'s ear in a constant position relative to the sound source, a small hearing-aid phone was held in a constant position about ¾ in. from his ear by means of earphone straps which fitted across the top of the head. The phone was

adjusted to direct the sound into the opening of the external meatus.

The psychophysical procedure consisted of a modified method of limits using only a descending series with the sound being attenuated in discrete 1-db steps. A ready signal, consisting of a small light turned on for 2 sec., was presented immediately before the sound. The *S* pressed a key after each sound to indicate whether he heard it. At near-threshold intensities most *S*s could not accurately detect when the sound went on but could reliably detect when it terminated. The duration of each sound presentation was 5 sec. After preliminary training, *S*s were trained until they could give ten successive threshold values with a range of 3 db or less. Most *S*s were able to meet this criterion quickly. Before the experimental period the threshold was again determined from five successive threshold values whose range was 3 db or less. The highest intensity level that *S* never reported hearing during the series of five measurements was taken as the subthreshold value to be used. After the conditioning period, which lasted an average of 1½ hr., the threshold was again checked by another set of five descending series. It was found that the subthreshold value remained constant for all but two *S*s whose subthreshold values had risen 1 db from the measurements made immediately before the conditioning period.

Selection of Ss.—Previous investigators have not indicated whether their *S*s were told the nature of the experiment. In the present study the exact nature of the experiment was explained to each *S* in order to make sure that he was aware of the importance of securing an accurate threshold measurement, and was sufficiently motivated for the tedious procedures involved. In addition, only *S*s who had "normal" hearing (as indicated by Maico standards) for the sound spectrum to be used in their particular phase of the experiment were employed. For example, if *S* had "normal" hearing at the points on the Maico scale of 1024 and 2048 cps he was used at the 2000-cps frequency. A similar criterion was used with the 200-cps value. If *S* was "normal" at 8192 and 11,584 cps, it was assumed that his hearing was "normal" at the 13,000-cps value. With the thermal noise, it was arbitrarily decided to use only those *S*s whose hearing measured "normal" at least between 512 and 5792 cps on the Maico scale. The slope of the average threshold curve indicates that these limits cover the range in which such a noise would be effective at the threshold level.

Conditioning procedure.—The CS was of 5-sec. duration and overlapped the UCS for the last ½ sec. The UCS lasted ½ sec. A predetermined patterning of reinforcement was not used because *E* wished to give reinforced and test trials (non-reinforced) whenever any consistency of response occurred on the record.

During a preliminary investigation some *S*s displayed variation in susceptibility of their GSR to conditioning to suprathreshold sounds. Therefore, each *S* in the major experiment was tested for suprathreshold conditioning immediately before an attempt was made to produce subthreshold conditioning. Suprathreshold conditioning was established to a sound 20 db above the subthreshold level. A criterion of three successive CR's of a magnitude of at least ½ the magnitude of the UCR was employed, and it was found that most *S*s reached this criterion with only two or three reinforced trials. As an added control, a suprathreshold sound was presented three or four times during the subthreshold conditioning period. This was to insure that the suprathreshold CR's had not become extinguished, or to show that *S*'s GSR still responded to a sound that was audible. In every case, it was found that a CR could be elicited without further reinforcement of the suprathreshold sound.

It is apparent that the number of *S*s employed and the length of the conditioning period, or number of reinforced trials given, would be contingent on the nature of the results obtained. It was decided that if no subthreshold conditioning was elicited for an *S* with one frequency, he would again be used with one of the other frequency values. If conditioning appeared to occur, it was planned to recheck this under similar conditions during another session. Thus, if none of the *S*s showed conditioning, each of them would be run with two frequencies. As no subthreshold conditioning was demonstrated, this was the procedure followed. A total of ten male *S*s was used and, since each *S* was run under two conditions, five *S*s were employed with each of the four conditions.

The length of the conditioning period was determined in a similar manner. As the GSR conditions rapidly to a suprathreshold sound it was decided that if subthreshold conditioning was not demonstrated, it would not be necessary to give an extended number of reinforced trials. On this basis, each *S* was given at least 20 reinforced trials during the subthreshold conditioning period. It seemed apparent that this would be sufficient to demonstrate conditioning if it could be obtained under the conditions of the experiment.

Results

The results of this study offer no evidence for the presence of subthreshold conditioning. While changes in

skin resistance occurred during the time interval of a few of the test trials on most of the records, the number of times they were present and their magnitudes were not sufficiently different from random activity to be interpreted as CR's.

The records were analyzed on the basis of the mean number of skin resistance changes and their mean magnitude (scaled in arbitrary units) during the test trials (5-sec. subthreshold CS interval) for the four frequency values employed, compared with a 5-sec. interval immediately before this period. The latter 5-sec. interval was used as an index of random activity. This analysis is shown in Table 1. It is clear that the mean number and magnitude of skin resistance changes occurring during the test trials were not appreciably greater than those during the comparison periods which were used as an index of random activity. The data in Table 1 also permit a comparison of the mean magnitude of skin resistance changes during the test trials and comparison periods with the mean magnitude of the CR's to the suprathreshold sound. While such a comparison is not entirely adequate, since the magnitude of the skin resistance changes are scaled in arbitrary units and have not been converted to some absolute scale, it is, however, clearly apparent that CR's to the suprathreshold sound are considerably larger than the skin resistance changes occurring on the records during the test trials and comparison periods.

The foregoing analysis was for each entire record. In order to determine whether there was any conditioning trend, a second analysis was made by dividing the records into two equal parts based on the number of test trials. When the number of test trials was uneven, the odd trial was allotted to the second half of each record. This analysis, which is presented in Table 2, shows no consistent differences between the mean number of skin resistance changes during the test trials on either of the two parts of the records.

Control Study

In the present study preconditioning was established to each frequency at an intensity 20 db above the sub-

TABLE 1

Mean Number and Magnitude of GSR's During the Test Trials and Comparison Periods with Subthreshold Stimuli and Mean Magnitude of Conditioned GSR's to the 20-db Suprathreshold Stimuli

$N = 5$ for each mean

Frequency of Auditory CS	Mean Number of Test Trials	Mean Number of GSR's				Mean Magnitude of GSR's				Mean Magnitude of Conditioned GSR's to 20-db Sound	
		Test Trial Period		Comparison Period		Test Trial Period		Comparison Period			
		Mean*	Range	Mean*	Range	Mean	Range	Mean	Range	Mean	Range
200 cps	31.8	5.5	0–8	3.5	0–10	1.5	0–2.5	1.1	0–2.0	7.4	5–10
2000 cps	33.8	3.9	0–7	3.8	0–6	1.3	0–2.0	0.8	0–1.5	9.0	6–15
13,000 cps	25.5	2.5	1–5	2.2	1–5	1.1	0–2.5	1.6	.5–2.0	9.6	6–17
Noise	30.8	4.7	0–8	3.5	0–9	1.1	0–2.0	0.5	0–1.5	10.6	6–20

* To compensate for the unequal number of test trials given *S*s, the following formula was used to compute the means: $M = \frac{\Sigma TN}{\Sigma T}$, where T = number of test trials, and N = value of measures for each *S*.

TABLE 2

MEAN NUMBER OF GSR'S DURING THE FIRST AND SECOND PARTS OF THE TEST TRIALS

Frequency of Auditory CS	Mean Number of Test Trials		Mean Number of GSR's			
			Part 1		Part 2	
	Part 1	Part 2	Mean	Range	Mean	Range
200 cps	14.0	14.9	1.8	0–4	2.8	0–4
2000 cps	16.6	17.2	2.0	0–4	1.4	0–3
13,000 cps	11.4	12.2	1.6	1–2	1.0	0–3
Noise	14.2	13.6	2.6	0–5	1.4	0–4

threshold level. The assumption was made that subthreshold conditioning, if it occurred, would have approximately the same rate of development and magnitude of CR as conditioning at the 20-db level. In other words, it was assumed that the intensity of the CS does not have an important effect on the rate of conditioning and the magnitude of the CR. Previous investigations partially support this assumption. In a series of papers dealing with various intensities of auditory CS's on the conditioning of GSR, Hovland (**10, 11, 12**) concluded that the strength of conditioning (rate of development and resistance to extinction) is not a function of the intensity of the CS. This conclusion has been supported by a study by Newhall and Sears (**17**), who conditioned finger withdrawal to near-threshold stimuli, and by Grant and Schneider (**6**) who were also working with the GSR. However, the data of Grant and Schneider indicate that the magnitude of the CR is related to the magnitude of the CS. As they were working with intensity levels from 76 to 106 db above threshold, their results can not necessarily be generalized to near-threshold intensity levels. Therefore the following control study was carried out to determine the effects of near-threshold CS's on the magnitude of the CR.

The procedure was basically the same as that employed in the main study except that the CS's were at various intensities above threshold. Each *S*'s threshold was measured and specified by the procedure described above. The CR's were then elicited in each of five *S*s to three intensities of a 2000-cps tone. The intensity levels were (*a*) 20 db above the subthreshold level, (*b*) 10 db above the subthreshold level, and (*c*) the lowest intensity sound that *S* could consistently hear. A partially counterbalanced design was used.

The results presented in Table 3 were obtained when the magnitudes of the CR's were scaled in arbitrary units. The intensity of the CS had no important observable effect on the magnitude of the CR. Therefore, it is reasonable to conclude that subthreshold conditioning, if it had occurred in the major experiment, should have had approximately the same rate of development and magnitude of CR as conditioning at the 20-db intensity level.

DISCUSSION

Under conditions which appear to be properly controlled no evidence was found which indicates that a frequency within the auditory range and at an

TABLE 3

COMPARISON OF THE MEAN MAGNITUDES OF CR'S AT EACH CS INTENSITY LEVEL IN THE CONTROL STUDY

S	Lowest Intensity Consistently Heard		10 db above Subthreshold Level		20 db above Subthreshold Level	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
1	6.6	1.9	5.2	2.1	6.3	1.7
2	7.2	1.6	10.1	2.4	5.8	1.8
3	9.1	2.2	12.6	1.9	10.6	2.3
4	6.7	2.3	5.9	1.1	7.3	2.1
5	10.1	1.4	11.5	2.2	8.8	2.0

* Nine test trials were given each *S* at each intensity level.

intensity that is below the absolute threshold can become a conditioned stimulus. The question arises as to how these results are related to the positive conclusion regarding subthreshold conditioning reported by Baker (**2**) and Metzner and Baker (**16**). Several possibilities are worth brief consideration. First, it may be that the pupillary light response can be conditioned to subthreshold tones, but for some reason not known, subthreshold conditioning is not possible with the GSR. Second, it is conceivable that Baker, and Metzner and Baker were working with an intensity level that was not subthreshold, and therefore the conditioning observed was actually to a suprathreshold CS. A third possibility is that the pupillary light responses that Baker and Metzner and Baker interpreted as CR's were merely random activity of the pupil, or ascribable to some other factor. On the basis of the available evidence we cannot completely accept or reject any of these possibilities, but as the evidence outlined above indicates that there is doubt that the pupillary light response can be conditioned at the suprathreshold level, the third possibility appears to be the most tenable.

An additional point worthy of consideration is that in this study a free-field procedure of presenting sound energy to the ear was used while Baker, and Metzner and Baker used earphones. As is well known, the free-field procedure yields threshold values that are appreciably below those obtained with earphones (**21**). This factor may indicate that an absolute threshold obtained with earphones is qualitatively different from one obtained under free-field conditions. In any event, the validity of subthreshold conditioning with the auditory modality cannot be accepted until more convincing evidence is available.

The conclusion drawn from this study applies only to the specific problem of subthreshold conditioning with the auditory modality. Whether subthreshold conditioning can be effected with other modalities is a question for future investigation. It should also be pointed out that even though subthreshold conditioning may not occur, this does not necessarily indicate that some sort of "subthreshold perception" can not occur. It may be that while such an effect can occur, subthreshold conditioning is not possible because the necessary neural connections can not be made for the formation of a CR. As the work of numerous investigators indicates the presence of subthreshold effects with various modalities (**14, 15**), this phase of the problem deserves more consideration.

Summary

An attempt was made to condition a change in skin resistance (GSR) of ten *Ss* using four separate frequencies with each at an intensity below the absolute threshold. The frequencies chosen were a 200, 2000, and 13,000 cps, and a thermal noise. The UCS was an electrical shock. The absolute threshold was specified as a range between (*a*) the lowest intensity level that *S* could consistently hear, and (*b*) the highest intensity level that *S* did not report hearing during five successive trials. The latter level was used as the intensity of the CS. Before each attempt at subthreshold conditioning, each *S*'s GSR was conditioned to a sound 20 db above the subthreshold level. A control study was run which indicated that for intensity levels within 20 db above the subthreshold level the intensity of the CS is not consistently related to the magnitude of the CR. The results indicate that no subthreshold CR's were elicited for any *S* with any of the four frequencies used.

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EFFECT OF INTERMITTENT LIGHT ON THE READABILITY OF PRINTED MATTER UNDER CONDITIONS OF DECREASING CONTRAST

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Since the total light energy of regularly phased intermittent light is independent of flash frequency, it has been generalized that the sensory effect of an intermittent eye illumination is likewise independent of flash frequency and follows the Talbot-Plateau law. Above the critical flicker frequency (CFF) the difference in brightness between a steady and an intermittent light depends upon the light-dark ratio (LDR) of intermittence only. This is also a function of aperture size, if rotating sectors are used in an experiment. If, on the other hand, the Talbot luminance of an intermittent light equals the luminance of a steady light, i.e., if the latter is balanced, no difference in apparent brightness is to be expected between the two types of light.

Below the CFF the relation between luminance and apparent brightness becomes reversed. As early as 1864, Brücke observed that at a frequency of 17.5 cps the white sectors of a rotating black and white disc appeared brighter than when stationary. Helmholtz had pointed out that the apparent brightness was not uniformly distributed over the disc area, and that the contrast between the bright and dark fields may cause the white to look brighter under these conditions.

A similar enhancement of apparent brightness can also be produced by using intermittent light; and this phenomenon has been studied extensively by Bartley (**1, 2, 3, 4**). Very soon, after the flash frequency dropped below the CFF, the subjective brightness of an intermittently illuminated field began to rise until it reached its maximum far above the Talbot level and that obtained with steady illumination. The maximum brightness obtained at about 8 to 10 cps is the reciprocal of the Talbot value. In this range, the sensory effect of intermittence is flicker. The enhanced sensation of brightness was always present when the surroundings of the test field were unilluminated (**2, 3, 6**).

A kind of a stereoscopic effect was also observed. Bartley noted that at a flash frequency of about 12 cps the characteristics of the test object appeared quite similar to those when a bright and dark field are viewed stereoscopically; he theorized that "it is in this portion, however, in which the dark and bright phases are to be seen simultaneously as though one overlaid the other, the aspect which most closely simulates the stereoscopic sensation. In stereoscopy the sensory messages of the two eyes are projected on the same cortical areas and effect either a blend, combination, or alternating dominance of one or the other, although the sensory messages themselves are streaming in simultaneously and continuously from both eyes to the point at which this takes place" (**2,** p. 475).

It is these two facts, namely Helmholtz's explanation of increased brightness contrast and the stereoscopic effect described by Bartley, which had previously suggested (**7**) that flicker can be used for increasing the visibil-

ity[1] of details of blurred and low-contrasting pictures, when illuminated by an intermittent light of a 9 to 15 cps frequency. Since no numerical evidence was available on this subject, an attempt was made to study the problem of utilizing the so-called Bartley effect for the improvement of visibility on a quantitative basis. For this, the experiment was designed to study and compare visibility under (*a*) steady and flicker conditions; (*b*) steady illumination with the total light energy and at the Talbot level; (*c*) at different flicker frequencies and LDR's.

Method

The method used was different from that used by Bartley (**1, 2, 3**) and Halstead (**6**), because the objective was to investigate the applicability of enhanced subjective brightness for the improvement of object identification under conditions of low contrast. Since brightness contrast was considered the critical factor, an Anoxia Demonstration Chart (Type AAF-L) developed by the Lighting Research Laboratory, General Electric Company, and the Army Air Force Materiel Command, Wright Field, Ohio, was used because of its suitable contrast characteristics (see Fig. 1). The luminous reflectance of the chart under steady illumination was measured as follows: Line 1, 33.2 ft.-L; Line 5, 29.5 ft.-L; Line 10, 24.5 ft.-L; Line 15, 19.3 ft.-L; Line 20, 13.6 ft.-L; Line 25, 9.9 ft.-L; Line 30, 8.8 ft.-L; Line 40, 6.8 ft.-L; and Line 50, 5.6 ft.-L.[2] This range is about the same as used by Bartley and Halstead in their experiments.

The chart (136 × 85 mm.) was illuminated either with steady or with flickering light. The *S* looked at the chart once under each condition. From a distance of 55 cm. he was required to read the text to that point at which he was unable to identify the words. Visual acuity required for reading the text without difficulty was about 20/30. The number of lines read was regarded as index of the visibility of details necessary for recognizing the print. In addition, reading time was recorded under both conditions of light. The order of steady and flicker readings was balanced throughout the experiment. Sixteen groups of 26 *S*s, each with normal visual acuity for near vision, participated; each group was used for only one pair of readings.

Flicker was produced by a motor-driven episcotister. Four aperture sizes (90°, 180°, 270°, 345°) and two flicker frequencies (9 and 15 cps) were used, one being close to the Bartley and the other to the Brücke maximum. The same light source was used for the steady illumination; the latter was measured as 15.4 ft.-candles before the experiment. In a second series of eight experiments the steady illumination was cut down to that of the intermittent one by high-speed rotating sectors (50 cps) having the same LDR characteristics and acting—as is well known—as equivalent filters; i.e., the second series in our experiment is a repetition of the first one with the luminance of the steady light at the Talbot levels of flicker.

Results

Table 1 presents the means and σ's of the means for the four aperture sizes of the rotating sectors (LDR's), the two flicker frequencies, and the two types of steady illumination. Each *S* read the chart twice, once under one of the eight flicker conditions, and once under either steady light with the fast rotating sector (called "equal") or under steady light without the rotating sector (called "unequal"), as indicated in the footnote to Table 1. The measure used here is the number of lines read by each *S* under steady light minus the number read under flicker.

Table 2 presents the results of an analysis of variance of the steady minus flicker differences. It is seen that the effect of aperture size, flicker frequency, and equality of total light energy are all statistically significant. In addition, the presence of significant interaction terms indicates that the differences are not uniform but vary with changes in aperture size. They do not vary particularly with changes in the other two variables. The large interaction mean square reflects the fact that while large differences exist

[1] The term "visibility" is used here in its psychophysiological sense meaning the detectability of, or the sensibility for, a visual stimulus.

[2] 1 ft.-L = 1.076 mL = 3.424 nit = 10.764 apostilb.

between flicker frequency and equality of lighting at small aperture sizes, these differences are negligible at large aperture sizes.

Since the effect of increasing the amount of light is also of interest, attention is directed to Table 1, Rows 3 and 4. There the mean number of

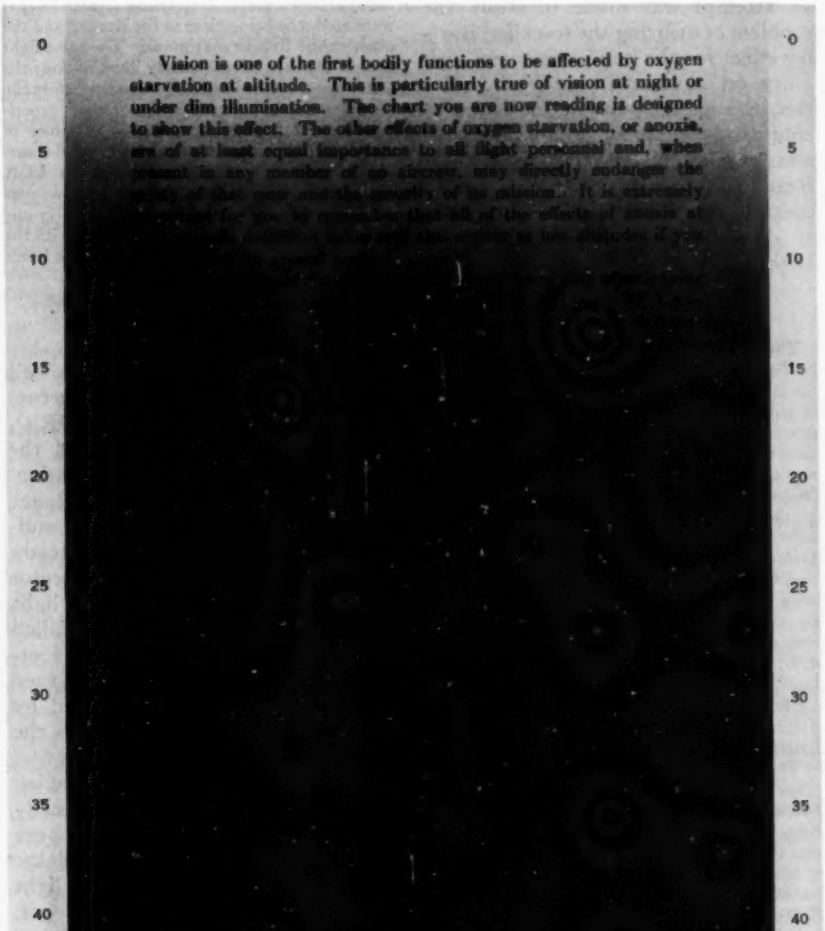
0
5
10
15
20
25
30
35
40
45
Vision is one of the first bodily functions to be affected by oxygen starvation at altitude. This is particularly true of vision at night or under dim illumination. The chart you are now reading is designed to show this effect. The other effects of oxygen starvation, or anoxia,

FIG. 1. The test chart

TABLE 1

MEAN NUMBER OF LINES READ UNDER FLICKERING AND STEADY LIGHT, BY APERTURE SIZE OF ROTATING SECTOR (LDR) AND FLICKER FREQUENCY*

Flicker Level	Aperture Size of Rotating Sector (LDR)							
	90°		180°		270°		345°	
	Mean	σ_m	Mean	σ_m	Mean	σ_m	Mean	σ_m
9 cps	15.5	.8	20.6	.8	21.2	.8	22.1	.6
15 cps	19.8	.7	20.3	.5	22.2	.5	21.2	.6
Steady, with rotating sector**	18.5	.8	19.4	.8	22.6	.6	21.7	.6
Steady, without rotating sector**	Mean = 23.2 σ_m = .3							

* Based on 52 observations except Row 4 where the mean is based on 208 observations.
** With rotating sector the amount of light is the same as in the two flicker cases. Without rotating sector the amount of light is greater than in any other case.

lines read are given for aperture sizes increasing from 90° to 345° in Row 3 and to 360° in Row 4. Using regression analysis with the analysis of variance, one can say (*a*) the number of lines read varies with the aperture size; (*b*) there is a significant linear increase in the number of lines read as aperture size increases; and (*c*) there is a departure from linearity at the 345° level. This may be due to an unnoticed decrease in luminance of the light source at the end of this series, however.

DISCUSSION

The results of the experiments indicate that throwing intermittent light on a reading chart having gradually decreasing contrast does not increase readability. Therefore the Bartley effect, if present, does not help to contrast the print on its background, because such an increase in brightness contrast would have improved necessarily the visibility of the text and thereby increased the number of lines read. What we found instead was a decrease in print visibility close to that produced by the "Talbot effect."

In accordance with Bartley (**1, 2, 3, 4**) we are inclined to assume that the effect named after him consists of an increase in brightness sensation which is strictly "subjective," i.e., without having any physical correlate. Without going into physiological theory we may hypothesize that this sensation may be brought forth by photochemical processes accompanying the slowly repeated flashes of intermittent light of a certain frequency. If one assumes that in case of this type of stimulation not only a sequential "on-effect" but also an additional "off-effect" occurs, a higher excitation level may be established, yielding an enhanced sensation

TABLE 2

ANALYSIS OF VARIANCE OF STEADY–FLICKER DIFFERENCES

Source	*df*	Mean Square	*F*
A (Aperture size)	3	182.1	17.6**
B (Flicker frequency)	1	69.5	6.1*
C (Equality of lighting)	1	297.8	28.8**
AB	3	48.2	4.7**
AC	3	51.8	5.0**
BC	1	11.1	1.1
ABC	3	44.5	4.3**
Error	400	10.3	
Total	415		

* Significant at .05 level.
** Significant at .01 level.

of brightness than in case of a steady stimulation. Recent studies on the characteristics of intermittent light stimulation seem to confirm this theory (**5**). This enhancement of brightness sensation, on the other hand, must not necessarily be construed as identical with an increased sensibility for the detection of visual stimuli.

It seems, then, permissible to theorize further that such an increase in excitation may, on the contrary, serve to decrease the detectability of weak signals; and this, in turn, would explain the loss ΔL-discrimination during flicker. As a matter of fact, flicker illumination resulted in a lower amount of lines read, and—if we are allowed to generalize from our results—in a higher discrimination threshold for finer details. This loss of detail visibility, however, may but apparently serve to enhance contrast in that the heavy features of a pattern stand out more distinctly under flicker than under steady illumination. This may account for the kind of sensations described in the introduction of this paper.

Summary and Conclusions

The utilization of the Bartley effect for the improvement of readability under conditions of low contrast was investigated. A reading chart with gradually decreasing brightness contrast was read under steady and flicker conditions with four different light-dark ratios and two flicker frequencies (9 and 15 cps). The number of lines read was accepted as index of readability and, in a more general way, as index of visibility under low $\Delta L/L$ conditions.

It was found that the effect of flicker was to lower the number of lines read especially at low illumination levels. For this reason it seems doubtful that flicker can be used for the improvement of visibility under conditions of low contrast.

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TEMPORAL NUMEROSITY: II. EVIDENCE FOR CENTRAL FACTORS INFLUENCING PERCEIVED NUMBER[1]

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The first paper in this series (**6**) reported the results of an investigation to determine the perceived number of flashes as a function of the number of flashes presented and the flash rate. It was found that the perceived number of flashes is fundamentally determined by, and definitely limited by, the time required for the presentation of a given train of flashes. It was also evident that the relationship between perceived number and elapsed time is not a simple one, but one which nevertheless shows a definite pattern.

The very slight degree of variability of response which was found led to the conclusion that what is involved is not a "judgment," but rather a perceptual process which tends to control visual information. The question arose as to whether this effect was brought about by some temporal characteristic of the retina or by some higher process. If the retina could be ruled out as the locus of such a process, the way would be opened for studies of a similar nature involving the other sense modalities to determine whether such an effect can be found other than in vision.

It was decided that the most direct way to approach this problem would be to study the human electroretinogram (ERG) produced by various rates of photic stimulation. Various workers have recorded the ERG to intermittent light (**1, 7**), but none have controlled the number of flashes and then compared the result with the perceived number. This approach seemed doubly worth while since some investigators (**4**, p. 278; **8**) have reported that the retina does not respond to every flash at fairly high rates of stimulation, while others (**9**, p. 71) report that the subcortical visual system can be driven well above fusion frequency.

Apparatus and Procedure

The apparatus used in this study has been described in some detail in a recent paper by Armington (**3**). The principal change made for the present study was in the shutter system. A series of sectored disks was constructed to be rotated by a constant speed (1 rps) motor. The duration of the light flash was kept constant (11 msec.), the various rates being obtained by leaving different intervals between the open sectors in each disk.

The *O* was kept in position by means of a biting board at a distance from the stimulus field such that the stimulus subtended a visual angle of 7.5°. The stimulus field was surrounded by a matte-white hemispherical screen illuminated to a level of approximately 2 ft.-L. The luminance value of the uninterrupted light beam was approximately 5.6 log units above 7 ft.-L. A 6-v., 18-amp. tungsten ribbon filament lamp was used as the light source. It was found that a decrease in the intensity did not affect the numerical character of the records, so neutral density filters were introduced in the system at various times to decrease the discomfort of *O*.

At the beginning of each recording session *O* was allowed to dark-adapt for 15 min. At the

[1] Navy Electronics Laboratory Professional Contribution No. 15. The writers wish to express their appreciation to Dr. Lorrin A. Riggs and the Psychology Department of Brown University for making their facilities available for this study and to the Office of Naval Research for the equipment made available to Brown University. A special note of thanks is due to Dr. E. Parker Johnson for serving as *O*.

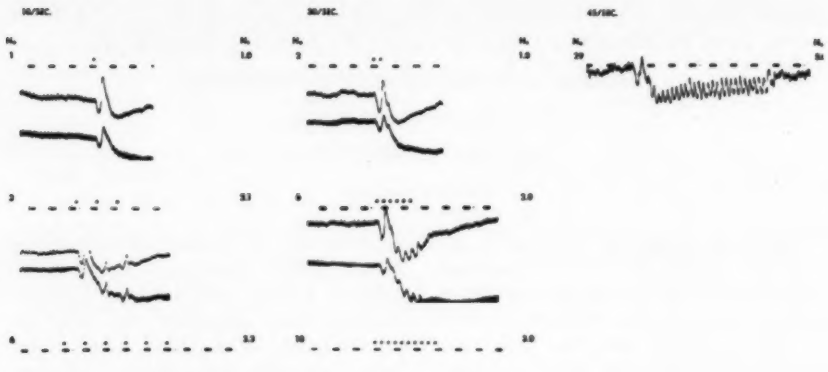

FIG. 1. Sample ERG records obtained with the three rates used in this study. N_0 indicates the number of flashes presented; N_s represents the mean perceived number for each number-rate combination. Time markings are at .1-sec. intervals. In the cases where two traces appear for each condition, the lower one is an unfiltered (direct coupled) record.

end of this time the surround was illuminated and *O* adapted to that level for 5 min. All the trains of flashes at a given rate were presented in sequence from low to high number, allowing about 30 sec. between each presentation. It did not seem necessary to work with all the rates of presentation used in the perceptual experiment (6), so only the 10/sec. and 30/sec. rates were duplicated. The results of the 30/sec. series indicated that a higher rate might be used to advantage, so 45/sec. was also tried. The stimulus arrangement used gave the same perceptual results as previously reported (6).

RESULTS

The major results of this study can be summarized by two statements: (*a*) the light-adapted retina reacted to every flash presented to it over the entire range of flash rates used in this experiment; (*b*) the electrical activity of the retina in response to intermittent stimulation did not bear any direct relationship to the perceived number of flashes, in a subfusional situation.

Sample records obtained with flash rates of 10/sec., 30/sec., and 45/sec. are presented in Fig. 1. The perceived numbers for each of the 10/sec. and 30/sec. presentations, taken from the earlier report on this topic, have been entered next to each record.

Once the main part of the experiment was completed, it was decided that it would be of interest to obtain records which would show the difference between the reaction of the photopic and the scotopic visual systems to the same numerical set of stimuli. A blue series of ten flashes at 30/sec. was presented to the eye after about 30 min. of dark adaptation, and a red series was later presented to the light-

adapted eye. These conditions were chosen as being optimum for the two types of response. Sample records for both conditions are shown in Fig. 2, along with the perceived number reported by *O* in each case.

Perceptual evidence for central interaction.—The results of the ERG studies, showing that the eye is capable of following every stimulus flash in the series used, removed the question of a limiting action at the retinal level. This leaves only the assumption that perceived number is limited by higher visual processes.

Further evidence for this type of limiting was obtained at the perceptual level by a stereoscopic presentation of flashes. The basic apparatus described in the first paper (6) was modified to allow either monocular presentation or alternating stereoscopic presentation of the flashes under the same conditions of stimulation. For the monocular conditions, the dominant eye was used, the flashes being presented on one side of the stereoscope only. The other eye remained open and saw only the surround without the flash. For the stereo-alternate condition, the flashes were alternated between the two eyes.

The method consisted of finding the number-rate combinations for which the objective flashes could be perceived correctly. It was necessary to go down to the lower rates of 7.5/sec., 5/sec., and 3.75/sec., since previous data showed that even two flashes at 10/sec. could not be perceived accurately at all times. The numbers used for monocular presentation were two flashes at 7.5/sec. and 5/sec., and two and three flashes at 3.75/sec., for which the perceived number agreed with the objective number. Next, these same number-rate combinations were used for the stereo-alternating condition. For example, four flashes were presented in such a way that each eye received only two at 7.5/sec., but were staggered in time so that the order was: first flash for the left eye, followed by the first flash for the right eye, then the second for the left, and the second for the right. The four flashes came at a rate of 15/sec. when combined stereoscopically. Thus the effective stereo-alternated stimulus for this flash series was four flashes at the rate of 15/sec. The same procedure was followed for the other numbers and rates.

TABLE 1

PERCEIVED NUMBER FOR MONOCULAR AND STEREO–ALTERNATE CONDITIONS

Monocular Condition			Stereo-Alternate Condition			
Flash Rate	N_0	N_s	Flash Rate		N_0	N_s
Dominant Eye			Each Eye	Combined		
3.75/sec.	2	2.0	3.75/sec.	7.5/sec.	4	3.0
3.75/sec.	3	3.0	3.75/sec.	7.5/sec.	6	4.0
5.00/sec.	2	2.0	5.00/sec.	10/sec.	4	3.0
7.50/sec.	2	2.0	7.50/sec.	15/sec.	4	2.4

The data for two *O*s, averages of ten readings each, are presented in Table 1. They do not represent a systematic study, but are given as a demonstration of interaction effects occurring at levels higher than the retina, and as supporting perceptual data for the ERG studies.

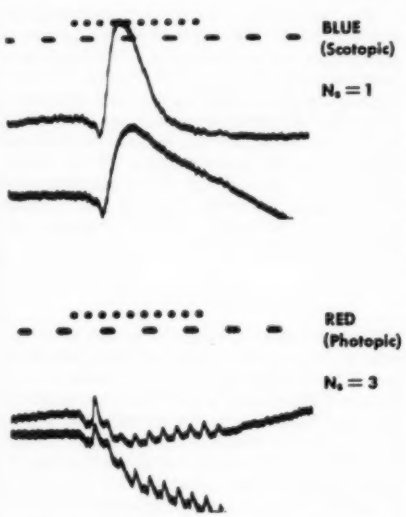

FIG. 2. Sample records presented to illustrate the differences in the scotopic and photopic responses to the same number-rate combination. Filters used were Farrand interference type having dominant wave lengths of 434 mμ and 643 mμ, respectively.

The data show that simple perceptual summation of objective flashes does not occur when these flashes, perceived correctly by each eye alone, are combined stereoscopically. The limiting of perceived number does not occur at the retinal level, but must be associated with some process taking place at a higher level of the visual system which is common to both eyes.

Discussion

Granting that the ERG reflects the over-all activity of the retina in response to photic stimulation, the results of the present experiment indicate clearly that the limitation of the perceived number of flashes cannot be accounted for by retinal action but must be ascribed to some higher process. This conclusion is strengthened by the results of the stereoscopic studies mentioned above. This finding does not agree with Bartley's contention that the subjective flash rate is lower than the stimulus rate because the retina cannot respond to every flash (**5**, p. 967). The fact that the subjective flash rate is essentially constant (6–8/sec.) regardless of stimulus rate from about 10/sec. up to fusion (**6**) also seems to indicate that there is some neural process, having a definite temporal pattern, which has some control on the visual input.

The records obtained in this experiment show quite clearly the difference between the photopic and scotopic components of the retinal response (**1**). The records in Fig. 2 show both components in a rather pure form, while in Fig. 1 the scotopic component can be seen as the initial large, slow response to a train of flashes, or at the slowest rate, as the very large first response. The results of the present study show clearly that the temporal pattern of numerosity which has been found is a function primarily of the photopic visual system, the scotopic system having an appreciable effect only during about the first 100 msec. The activity of the scotopic system probably accounts for the fusion noted during this time for the higher rates. This fusion, therefore, can probably be eliminated by increasing the brightness of the adapting field.

At the present time it may be fruitless to conjecture as to exactly what neural process acts to control the visual input, but several types of neurophysiological studies that have been made are quite suggestive along this line. Adrian and Matthews (**2**), for example, reported that the EEG response to intermittent light, recorded from the human occipital region, followed the stimuli up to at least 25/sec. This value was not a limit, but merely the highest rate tried by these workers. More recently, Halstead (**9**) has summarized a number of studies which tend to show that the visual system may follow an intermittent stimulus at rates above fusion frequency. On the basis of his work, he believes that perceptual fusion is controlled in some way by the frontal lobes.

The fact that the numerosity phenomenon is so highly predictable makes it interesting from a purely behavioral point of view. Much valuable information can be gained by studying it as a response, with no regard to its neural correlates. A number of additional studies are now under way at this laboratory as a result of the findings reported in the present paper. Flash rates higher than 30/sec. are being studied, and arrangements are being made so that similar studies may be carried out for auditory and vibratory stimulation.

Summary

The purpose of this experiment was to determine if the perceived number of flashes was limited by temporal characteristics of the retina. Human ERG records were studied to ascertain the relationship of retinal response to the objective number of flashes at several flash rates. The ERG results showed that the light-adapted retina reacted to each separate flash in a series of flashes, up to the highest flash rate used, 45/sec.

It was concluded that the retina is not responsible for the temporal patterning of perceived number, but that this phenomenon must be determined by some higher process. Perceptual data from stereoscopic studies supported the conclusions based on the ERG results.

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ROTE MEMORIZATION, UNDERSTANDING, AND TRANSFER: AN EXTENSION OF KATONA'S CARD-TRICK EXPERIMENTS[1]

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In his experimenting and theorizing, Katona (**2, 3**) distinguishes between "senseless" and "meaningful" learning, largely by contrasting the results of rote memorization with those of learning by understanding. Because some such distinction is implied in much contemporary learning theory, particularly in arguments centering around stimulus-response interpretations, on the one hand, and cognitive interpretations, on the other, it seemed pertinent to repeat some of Katona's experiments under conditions which might meet the criticisms of them (e.g., Melton, **4**), and at the same time might add additional dimensions to the investigation of problem-solving behavior.

We wished to test experimentally three generalizations from Katona's work: (*a*) The advantage of learning with understanding does not necessarily show up in original learning, for learning with understanding may take longer than learning by rote. (*b*) Retention after learning by understanding tends to be greater than retention after learning by rote. (*c*) Transfer to new related tasks is greater after learning by understanding than after learning by rote.

[1] This experiment is one in a series of studies of problem-solving being done under Project NR 150–104 and supported by Contract Nonr 225 (02) between Stanford University and the Office of Naval Research. Work on the contract is now under the general direction of Dr. Donald W. Taylor. Permission is granted for reproduction, translation, publication, use, and disposal of this article in whole or in part by or for the United States Government.

We chose to begin with card tricks designed after those used by Katona, preserving the essential characteristics of his experiments but modifying them in procedural detail in order to simplify statistical treatment.

Method

The *S*s for the experiment were 60 high school students from Palo Alto and Redwood City, California, who came to the laboratory individually on two successive days. The experiment was conducted during the summer vacation period in 1952, and *S*s received pay for their services. The *S*s were assigned alternately to each of two groups, so that a random distribution between groups might be achieved. One group, known as the Memorization Group, learned by rote memorization on the first day; the other, the Understanding Group, was taught a rational method on the first day. The two groups were treated alike on the second day, in tests for both retention and transfer. Differences between the groups on the second day were interpreted as due to differences in what they learned on the first day.

The card tricks have been described in detail by Katona (**2**, pp. 263–264). In order to do any one of the tricks *S* has to arrange a fixed number of playing cards in a correct order so that, when he plays them from the hand in a prescribed manner, they will appear on the table in the plan of the trick. For example, he may have to arrange the cards so that when he plays the top card face up on the table, then plays the second card to the bottom of the pack held in his hand, plays the third card face up, the next to the bottom of the pack, and so on alternately until all are played, the cards played face up will be in the order ace, "2," "3," and so on for the number of cards in the hand. In another variation the trick demands that the cards turn up alternately red and black. Other variations call for odd- and even-numbered cards in a prescribed order, or, instead of skipping one card, two cards may be played to the bottom of the pack between the cards played face up on the table. The

number of cards in the pack may be changed, thus changing the initial order, even though the same general outcome is called for. All the tricks are alike in that each calls for a fixed order of cards in the pack, and none requires special manipulative skill. The tricks are difficult only because the cards played to the bottom of the pack are reused in later runs through the pack, and so the original arrangement in the pack is not immediately obvious.

In order to show *S* the general requirements of the tricks, *E* began by demonstrating a trick with 13 spades pre-arranged in preparation for the demonstration. He had prepared the pack in the order A-Q-2-8-3-J-4-9-5-K-6-10-7. He held the cards face down, with the back of the ace face up on the table, then, without showing what card it was, he placed the second card at the bottom of the pack held in his hand. Then he played the next card, a "2," face up. He placed the next card on the bottom, following the practice of skipping one card each time between those played face up on the table. Continuing in this way, alternately playing a card and skipping one, he came out with all of the cards in the proper order on the table. This trick is named "13 spades; skip one."

The first trick that *E* proposed to teach *S* was one using four red cards and four black cards. He showed *S* how to arrange the cards so that as he played them alternately face up on the table and to the bottom of the pack they would appear alternately red and black on the table, i.e., turning up in the order R-B-R-B-R-B-R-B. This trick is called "4 red, 4 black; skip one." The solution is to arrange the cards in the order: R-R-B-R-R-B-B-B.

The *E* introduced a difference in treatment between the Memorization Group and the Understanding Group through the manner in which he taught this first trick. To an *S* assigned to the Memorization Group he simply gave the order of red and black cards for the solution. The *S* learned the order by rote, and then arranged the cards and performed the trick. Occasionally he made errors, such as reversing the order by placing the top card on the bottom. The *E* pointed out and corrected any errors. The *E* recorded the time required to teach the trick, from the beginning of instructions to a perfect performance of the trick.

Instead of giving the correct order, *E* showed *S*s in the Understanding Group how to derive the order, following a written scheme suggested by Katona (**2**, page 264):

Scheme for Determining Correct Order of Cards

1.	?	?	?	?	?	?	?	?
2.	R	?	B	?	R	?	B	?
3.		R		?		B		?
4.				R				?
5.								B
6.	R	R	B	R	R	B	B	B

In this scheme, the question marks represent unknown cards. Originally, all eight cards are unknown, as in Row 1. The first time through, we know that the alternate cards must be red (R) and black (B), as in Row 2. The four cards remaining in the hand are still unknown, shown by the question marks of Row 2. We know that the first of these remaining cards must be red, the third black. This information is recorded in Row 3. There are still two unknown cards remaining. In Row 4 we assign red to the first of these, leaving black for the remaining card, Row 5. In Row 6 we summarize all that we did above, and have the solution.

After *E* had shown *S* how to do this, he asked him to repeat the solution with pencil and paper, and then to arrange the cards in the pack and do the trick. The *E* answered any questions that came up, and pointed out and helped *S* to correct errors. The *E* recorded the total time required to teach the successful trick to *S*.

The order of tasks was alike for both groups of *S*s on the two days of the experiment, as follows:

Day 1

Foredemonstration by *E:* 13 spades; skip one.
Task 1: 4 red, 4 black; skip one. (*Solution:* R-R-B-R-R-B-B-B.)
Task 2: 8 spades; skip one. (*Solution:* A-5-2-7-3-6-4-8.)

Day 2

Foredemonstration by *E:* 13 spades; skip one.
Retest of Task 1: 4 red, 4 black; skip one.
Retest of Task 2: 8 spades; skip one.
Task 3 (transfer by transposition): 4 even, 4 odd; skip one. (*Solution:* E-E-O-E-E-O-O-O.)
Task 4 (transfer involving problem-solving): 3 red, 3 black; skip one. (*Solution:* R-B-B-B-R-R.)
Task 5: 4 red, 4 black; skip two. (*Solution:* R-R-B-B-B-B-R-R.)
Task 6: 10 spades; skip two. (*Solution:* A-10-8-2-5-7-3-9-6-4.)

The rationale of the order of tasks is fairly evident. It seemed to us desirable to use at least two forms of the problem in the memorization series in order to set the stage for the transfer experiments to follow. The foredemonstration was repeated on Day 2 so that there would be no ambiguity about what was called for in the tricks *S*s were asked to recall. On Day 1 both tasks were learned to the point of a perfect performance of the tasks. Task 1 was retested immediately following the foredemonstration in Day 2. Because our primary interest centered on transfer, any *S* who made errors in the retest on Task 1 was retrained to a perfect performance before going to Task 2. This means that the retest on Task 2 may have been aided by help given on Task 1. If there were errors on Task 2, it was also retaught, so that the transfer tests to follow would be based on prior learning that had been recently correct in its outcome.

In the transfer tasks *E* simply gave *S* the appropriate cards and told him to arrange them, if he could, in such a way as to satisfy the

requirements of the assigned trick. A time limit of 2 min. was imposed on both the retention and the transfer tasks. The limit was imposed so that *Ss* of the Memorization Group would not have time to discover and learn for themselves rational methods similar to those taught *Ss* of the Understanding Group. Few *Ss* of the Understanding Group were handicapped by the time limit; most of them who did not finish in the 2 min. allowed were not using correctly the method taught. If an *S* did not complete the transfer task in the allotted time, or finished it incorrectly, he went right on to the next task. In order to avoid excessive frustration, *Ss* of the Memorization Group were taught a rational solution to the problems after completing the experiment on the second day. Data were not recorded from these postexperimental trials.

It will be noted that the transfer tasks are of two kinds, planned to have several degrees of difficulty. Task 3 illustrates transfer by simple transposition, with even- and odd-numbered cards substituted for the previously learned red and black cards. It was conjectured that the Memorization Group had a fair chance to make this transfer on the basis of the order they had memorized. Tasks 4, 5, and 6 do not permit a simple transposition, and for them the Understanding Group has a logical advantage. The method taught the Understanding Group is applicable, provided it is really understood.

Task 4 resembles Task 1, but the change in number of cards changes the order. It is easy enough, however, that a little trial-and-error behavior can produce the necessary rearrangement. Tasks 5 and 6, by introducing the skipping of two cards instead of one, are by all odds the most difficult. Logically, however, the solution taught the Understanding Group was readily applicable to each of these tasks.

Results

Ease of memorization vs. ease of learning by understanding.—Because the orders of cards to be memorized were very easy, the original tasks were learned much more quickly by the Memorization Group than by the Understanding Group. The Understanding Group had to learn a pencil-and-paper method of diagramming the order of the cards on the basis of the requirements of the problem. Because the Understanding Group took longer on both tasks than the Memorization Group, it is probably unwise to say that the amount of practice was equated, even though both mastered the tasks satisfactorily before completing the first day's training. The times required for mastering both tasks by the two groups are given in Table 1.

It is evident from Table 1 that the Understanding Group was slow in learning what was required for the solution of Task 1, but that some economy had already entered by the time Task 2 was attempted. Even so, the Understanding Group was behind the Memorization Group on both tasks. This result agrees with Katona's findings; it serves as a warning that if there are advantages to learning by understanding they do not rest in any universal advantage in ease of acquisition.

Overnight retention.—The *Ss* were warned at the end of Day 1 not to think about or practice what they had learned, and they were questioned about it at the beginning of Day 2. The *Ss* appeared to be acting in good faith, and no evidence of rehearsal was found. The results for the overnight retention tests on Tasks 1 and 2 are given in Table 2.

We see that the one-day retention gives no advantage to the Understanding Group for the retention of Task 1, which is uncontaminated by new learning. The advantage of the Understanding Group on Task 2, which is

TABLE 1

Time (in Seconds) Required to Master Task 1 and Task 2 on Day 1

Group	*N*	Task 1*		Task 2**	
		Mean	*SD*	Mean	*SD*
Memorization	30	130	52	123	52
Understanding	30	435	263	202	115

* 4 red, 4 black; skip one.
** 8 spades; skip one.

barely significant statistically, may have arisen in part from the retraining on Task 1 of those who failed to solve that task immediately. These results contradict Katona's generalization that learning with understanding is better retained than learning by rote. The interval between learning and retention is so short, however, that the test is perhaps not entirely satisfactory. There were an appreciable number of *Ss* in both groups who made errors, so that the result does not depend upon overlearning. As many of these errors were made in the Understanding Group as in the Memorization Group. If one group should have had an initial advantage over the other, it was the Understanding Group because of the extra time used in learning on Day 1.

Transfer by simple transposition.—Task 3 required simply that for the familiar order of red and black cards there be substituted a similar order of odd and even cards. This substitution was as possible for the memorization *Ss* as for those trained with understanding, although they had to discover the possibility for themselves. Even so, the Understanding Group appeared to have a slight advantage. Seventeen of 30 *Ss* in the Memorization Group failed to make a perfect score on Task 3; however, 10 of 30 *Ss* in the Understanding Group also failed, so that the statistical significance of the difference is marginal ($p = .06$, see footnote to Table 2).

TABLE 2

NUMBER OF *Ss* MAKING PERFECT OVERNIGHT RETENTION SCORES ON TASKS 1 AND 2

Group	*N*	Task 1	Task 2
Memorization	30	22	21
Understanding	30	23	27
Probability of this difference arising by chance*		1.00	.05

* Determined by computing the exact probabilities from the fourfold table based on success and failure. Corresponds approximately to a one-tailed test of χ^2. See Fisher (1, pp. 100–102).

TABLE 3

NUMBER OF *Ss* MAKING PERFECT SCORES ON PROBLEM-SOLVING TASKS 4, 5, AND 6

Group	*N*	Task 4 *3 Red, 3 Black; Skip One*	Task 5 *4 Red, 4 Black; Skip Two*	Task 6 *10 Spades; Skip Two*
Memorization	30	3	1	1
Understanding	30	16	7	10
Probability of this difference arising by chance*		.0003	.03	.003

* See note to Table 2.

Transfer involving problem-solving.—The next three transfer tasks all involved problem-solving; that is, they could not be performed through simple transposition of the formula known to the Memorization Group, although they could be worked out by an adaptation of the method known to the Understanding Group. As shown in Table 3, the Understanding Group had an advantage throughout, thus fully substantiating Katona's findings on transfer.

The success of the Understanding Group was relative only. Perhaps the most striking feature of the table is the relatively poor success of the Understanding Group, even though it did better than the Memorization Group. Only on Task 4 were as many as half the Understanding Group successful.

The evident increase in difficulty for the Understanding Group between Task 4 and the next two tasks came with the requirement of skipping two, after having been taught to skip one. The contrast is, therefore, not simply that between memorization and understanding. There are apparently degrees of understanding that must be taken into consideration.

DISCUSSION

The experiments were designed primarily to study the ease of transfer after

learning by memorization and by understanding. Katona's finding of significantly greater transfer after learning by understanding is borne out. The fact that original learning took longer for the Understanding Group than for the Memorization Group is in part a function of the mechanics of instruction necessary to teach the understanding method. The failure of the Understanding Group to show advantage in overnight retention remains to be accounted for, along with the failures of many members of the Understanding Group to solve the transfer problems. The failures of the Understanding Group are more impressive than their successes, in view of the logical advantages inherent in the methods they were taught.

Errors by *S*s of the Understanding Group fall into several classes:

1. Some *S*s, impatient with the understanding method, adopted the rote memorization method once the answer was achieved. On the retest they attempted to remember the solution from the day before, rather than to go about reconstructing it. Hence they made the same kinds of errors *S*s of the Memorization Group made.

2. Careless errors were very common among these high school students. Even though they understood the method of diagramming the order of the cards, they frequently skipped spaces improperly, especially when moving from one row of their diagram to the next. Such errors often persisted in later trials, even after attention had been drawn to them and they had been corrected on earlier trials.

3. Confusion was occasionally due to partial understanding, partial reliance on rote learning. A device that gives understanding to one who fully sees the relationships involved may be used as a formula or a crutch by one who has not fully grasped the essential relationships. It was possible to teach the "understanding method" so that it could be used successfully with the first two tasks without its being understood in the fuller sense.

The confusion and errors on the part of the Understanding Group set a number of problems for further investigation. Several different methods of making a rational approach to these card tricks have been devised, such as working backwards, or using numbered slips of paper in determining the order of cards. Further experiments are under way in order to determine the conditions under which more adequate understanding is achieved.

Summary

Some of Katona's card-trick experiments were repeated with 60 high school students assigned to two groups (a Memorization Group and an Understanding Group). The experimentation was done individually.

The following results were obtained:

1. More time was required to teach the problems initially to the Understanding Group than to the Memorization Group.

2. Overnight retention was equal for both groups, although many retention errors were made even over this relatively short interval. After the first retention task was relearned, the retention test for the second task favored the Understanding Group.

3. Transfer to a task requiring simple transposition, therefore logically soluble on the basis of prior experience by both groups, led to considerable transfer by both groups, but the Understanding Group achieved greater success than the Memorization Group, a result of marginal statistical significance.

4. Transfer to three tasks requiring problem-solving all favored the Understanding Group by significant amounts.

5. Large numbers of errors were made by members of the Understanding Group. These are attributed to (*a*) reliance on rote memory when logical solution was possible, (*b*) careless errors within an understood approach, and (*c*) confusion due to partial understanding, insufficient to mediate more difficult transfer.

Failure to find an advantage in retention for the Understanding Group over the Memorization Group contradicts one of Katona's generalizations. The findings on transfer confirm Katona's generalizations about the superiority of understanding over rote memorization.

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EXPERIMENTS ON SENSORY-TONIC FIELD THEORY OF PERCEPTION: VI. EFFECT OF POSITION OF HEAD, EYES, AND OF OBJECT ON POSITION OF THE APPARENT MEDIAN PLANE[1]

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In the earlier studies of this series the constructs of sensory-tonic field theory have been of heuristic value within the problem area of apparent verticality (**6, 7, 8, 10, 12**). In the present study these constructs are applied to another dimension of space, namely, that of the median plane (straight-ahead).

One has to distinguish between two concepts of the median plane, viz., the objective median plane, which is physically defined, and the apparent median plane, which is perceptually defined. The objective median plane relates to a bodily dimension, i.e., it is a plane coinciding with the median sagittal section of the body; the apparent median plane refers to that position in space which is experienced as straight-ahead.

It has been previously shown that "extraneous stimulation," i.e., stimulation from a source other than the object attended, affects the perception of verticality in a specific manner. To illustrate, if extraneous stimulation is applied in the form of body tilt of 15° to one side, while adjusting a rod to apparent verticality, the position of the apparent vertical shifts to the opposite side. Such effects were found to exist for visually as well as kinesthetically perceived verticality (**6**). Furthermore, the effects of extraneous stimulation have been contrasted with the effects of stimulation coming from the object attended to. In contrast to the effect of asymmetrically applied extraneous stimulation it was found that the asymmetrical position of an object (a tilted line) shifts the position of apparent vertical in the direction of the tilt (**10**). In pursuing the generalization of the effects of extraneous and object stimulation further, studies reported here attempt to show that there are effects of extraneous as well as object stimulation on the position of the apparent median plane analogous to those on apparent verticality.

If the findings concerning the effects on the vertical are translated to another dimension of space, the median plane, the following hypotheses can be made: (*a*) Hypothesis concerning object stimulation: It is expected that the position of the apparent median plane will shift in the direction toward the side at which the fixated object is located. (*b*) Hypothesis concerning extraneous stimulation: In contrast, with eyes closed, when the head or eyes are turned around the vertical axis of the body to the left, the position of the apparent median plane should shift relatively to the right, and when the head or eyes are turned to the right, the apparent median plane should shift relatively to the left. It should be noted that the closing of the eyes is a prerequisite to make eye turning function as extraneous stimulation because it involves muscular changes without reference to an object.

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Two experiments were conducted to test these hypotheses. In both experiments the methodology of "pointing" was employed, i.e., the position of the apparent median plane was measured by having *S*, in a dark room, point to a location on a wall in front of him which appeared "straight-ahead."

Experiment I

This experiment was concerned with the effect of location of a fixated object on the position of the apparent median plane.

Procedure.—The *S* stood erect at arm's length from a wall in a dark room so that the median sagittal plane of his body was perpendicular to the wall (see Fig. 1). A screen having a horizontal and a vertical section was used; the vertical section was in the frontoparallel plane at a distance of 40 cm. from *S*'s eyes. The screen insured that *S* did not see movements of his arm. The apparatus was aligned in such a way that an imaginary vertical plane, passing through the center of a chin rest and the center of the vertical section of the screen was perpendicular to the wall (Fig. 1. Top View). The *S* was positioned with head held in place by the chin rest and with feet in Romberg position (close together) so that the median sagittal plane of his head and body coincided with the vertical plane mentioned above. Thus the objective median plane was determined by projecting the median sagittal plane of *S*'s head and body upon the frontoparallel plane (wall). The *S* was cautioned not to move once he was positioned in space; a luminescent marker in the middle of *S*'s occiput and a perpendicular indicator in the objective median plane provided a check throughout the experiment on the maintenance of straight-forward head position. The object to be fixated consisted of a 1.2-cm. luminescent square which was fastened at eye level to the vertical section of the suspended screen in each of three places, viz., in the objective median plane, 15° left, and 15° right of objective median plane.

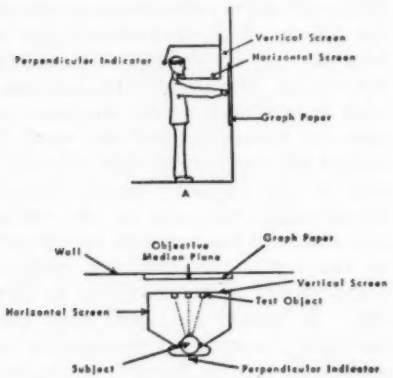

Fig. 1. Sketch of *S* positioned in apparatus: A. Side view; B. Top view.

The *S* was requested to mark with a rubber stamp in his right hand a place on the wall which appeared to be straight-in-front of him. He was informed that straight-in-front meant any point where the median sagittal plane of his head and body projected on the wall, e.g., where he felt that his nose would project on the wall. The *S*'s markings appeared on a large sheet of graph paper mounted on the wall; deviations of these marks from the vertical line designating the location of the objective median plane were used as measures. Arbitrarily, positions to the left of the objective median plane were designated by minus values and positions to the right of the objective median plane were designated by plus values.

The task was carried out under three experimental conditions of fixation of the luminescent square: (*a*) square 15° to left of objective median plane; (*b*) square at objective median plane; and (*c*) square 15° to right of objective median plane. Each *S* was tested under each of the three positions of the square. One trial was used for each condition. For each *S* one of the six possible sequences (abc, acb, bac, etc.) was used. Six *S*s, 3 male and 3 female, were tested in each sequence making a total of 36 *S*s. This combination of latin square and factorial design is discussed by Kogan (4).

Results.—Table 1 presents the analysis of variance including *t* tests. The *F* test for experimental conditions is significant beyond the .05 level of confidence. In accordance with expectation the position of the apparent median plane shifts relatively to the left (−.1 cm.) when the fixated object is to the left, and relatively to the right (+ 5.1 cm.) when the fixated object is to the right. The position of the apparent median plane under fixation of the object placed in the

objective median plane (+ 1.4 cm.) is between the positions for the other two experimental conditions. The mean for left-fixation is significantly different from right-fixation; the mean for center-fixation differs significantly from the mean for right-fixation; the means for center-fixation and left-fixation do not differ significantly.

It may be noted that the *F* test for sequence is significant, suggesting the importance of control of this variable. In addition the *F* test for individuals (within sex and sequence) is significant; this touches upon the question of stability of individual differences with respect to the straight-ahead, analogous to that previously reported for perception of verticality (**7**).

Experiment II

This experiment was concerned with the effect of head and eye position on the position of the apparent median plane.

Procedure.—A methodology similar to that of the first experiment was employed. The *S* was blindfolded, standing erect at arm's length from a wall; the median sagittal plane of his body was again kept perpendicular to the wall; *S* stood with feet in Romberg position at a place marked on the floor.

As in the first experiment, *S* marked a place on the wall which appeared to be straight-in-front of him. He was informed that straight-forward meant any point where the median sagittal plane of his trunk projected on the wall. The *S*'s markings appeared on a large sheet of graph paper and the deviations of these marks from the objective median plane (projection of the median sagittal plane of his body on the wall) were the measures used.

The task was carried out under five experimental conditions: (*a*) Control: head and eyes in straight-forward position; (*b*) Eyes left: head forward and eyes turned to the left; (*c*) Eyes right: head forward and eyes turned to the right; (*d*) Head left: head turned to left and eyes straight-forward with respect to head position; (*e*) Head right: head turned to right and eyes straight-forward with respect to head position.

It should be noted that the *S*'s determination of the straight-forward under the two principal conditions, eye turn and head turn, cannot be considered to be entirely identical. Under conditions of eye turning the median sagittal planes of head and trunk coincide; under conditions of head turning the median sagittal planes of head and trunk do not coincide. We therefore specify that the instruction given to *S*, viz., "straight-forward" refers to where the median sagittal plane of the trunk projects on the wall, "refers to head and trunk under conditions of eye turning, and to trunk under head turning conditions."

Each *S* was given one trial under each of the five experimental conditions. A replicated 5 × 5 latin-square design was used (**3**). Twenty *S*s were tested, two men and two women in each of the five sequences.

TABLE 1

Effect of Location of a Fixated Object on the Position of the Apparent Median Plane

F Tests

Source of Variation	*df*	Mean Square	*F*	*p*
Between all individuals	35	86.24	—	—
Sex	1	15.26	<1.00*	>.05
Sequence	5	183.90	2.56*	<.05
Individuals within sex and sequence	29	71.85	1.75	<.05
Conditions	2	158.36	3.85	<.05
Ordinality	2	22.82	<1.00	>.05
Error	68	41.11		
Total	107			

t Tests† (*Mean Differences*)

Location of Object	Means (Cm.)	In OMP	15° Right of OMP
15° Left of OMP‡	− .1	1.5	5.2§
In OMP	+1.4	—	3.7§
15° Right of OMP	+5.1		—

* Tested against individuals within sex and sequence.
† The standard error of the difference used in computing *t* was derived from the error variance (*df* = 68) as indicated in the *F* table.
‡ Objective median plane.
§ $p < .01$ (one-tailed test).

Results.—The analysis of variance, including *t* tests, is presented in Table 2. The *F* test for conditions is significant beyond the .01 level of confidence. In accordance with expectation, the position of the apparent median plane shifts relatively to the left for eyes right as well as for head right, and relatively to the right for eyes left and for head left. There are no significant

differences between the effects of head turning to the left and eye turning to the left; this also holds for the differences between head turning to the right and eye turning to the right. Table 2 also shows that the position of the apparent median plane under the control condition falls between the positions of the apparent median plane under left versus right head (eye) turning. These differences are significant.

We should like to draw attention to two further points in the results: (*a*) The mean position of the apparent median plane is consistently to the right of the objective median plane. Whether this is due to some characteristic tendencies of the *Ss*, to the use of the right hand by the *Ss*, or some other factor remains a matter for further empirical study. In this particular study, however, our hypothesis is concerned with the relative shifts due to left compared with right head and eye turning. (*b*) The *F* tests for ordinality and for *Ss* (within sex and sequence) are significant. Both of these variables point to systematic effects (i.e., shifts in pointing dependent upon temporal position of trial; stability of individual differences) which may provide a worth-while area of investigation.

TABLE 2

EFFECT OF EXTRANEOUS STIMULATION (HEAD AND EYE POSITIONING) ON THE POSITION OF THE APPARENT MEDIAN PLANE

F Tests

Source of Variation	*df*	Mean Square	*F*	*p*
Between all individuals	19	107.10	—	—
Sequence	4	101.01	<1.00*	>.05
Sex	1	58.89	<1.00*	>.05
Individuals within sex and sequence	14	112.28	15.38	<.01
Conditions	4	124.89	17.11	<.01
Ordinality	4	35.72	4.89	<.01
Square uniqueness	12	12.01	1.65	>.05
Error	60	7.30		
Total	99			

t Tests† *(Mean Differences)*

Conditions	Mean (Cm.)	Eyes Right	Control	Eyes Left	Head Left
Head Right	1.0	1.2	2.8§	4.8§	6.1§
Eyes Right	2.2	—	1.6‡	3.6§	4.9§
Control	3.8		—	2.0§	3.3§
Eyes Left	5.8			—	1.3
Head Left	7.1				—

* Tested against individuals within sex and sequence.
† The standard error of the difference used in computing *t* was derived from the error variance ($df = 60$) as indicated in the analysis of variance.
‡ $.05 > p > .01$ (one-tailed test).
§ $p < .01$ (one-tailed test).

DISCUSSION

The results of the first experiment demonstrate systematic shifts of the position of the apparent median plane depending on the location of the fixated object: these shifts are in the direction of the location of the fixated object. The second experiment demonstrates shifts of the position of the apparent median plane under conditions of eyes closed, depending on left versus right head positions and left versus right eye positions. The position of the apparent median plane shifts in the direction opposite that of head turn and eye turn.

These results have been predicted from studies on verticality where it was demonstrated that stimuli defined as object stimuli and those defined as extraneous stimuli have opposite effects on the physical position perceived as vertical; in particular, it was found that the position of apparent vertical is closer to the side to which a line is initially tilted and opposite the side to which the body is tilted.

The findings concerning apparent verticality are in correspondence with the two main results of the present study, i.e., the lateral placement of a fixated object can be considered analogous in its effect on the median plane to the effect of a tilted object on verticality; similarly, torsion of the head or eyes around the vertical axis of the body can be considered analogous in its effect on the median plane to the effect of body tilt on verticality.

We have viewed the effects on verticality in terms of the interrelation between stimuli coming from the object and

organismic state (**9, 11**). For further clarification we may briefly summarize the general assumptions involved in the conceptualization pertaining to perceived localization in space.

The primary assumption is that the experience of "apparent vertical"—and similarly that of "apparent median plane"—parallels a particular relation obtaining between "stimuli from an object" and organismic state. Before going further, it should be emphasized that the term "stimuli from an object" has a special connotation here; it is used because we distinguish between two kinds of stimuli, object stimuli and extraneous stimuli. The principal distinction between these two types of stimuli is this: We are dealing with object stimuli if the observer is directed to, or attends to such stimuli qua signs of an object; extraneous stimuli, on the other hand, are stimuli from a source not attended to as an object. For instance, if *S* is given the task to observe the position of a line while being subjected to auditory stimulation, the visual stimuli issuing from the line are object stimuli and the auditory stimuli are extraneous; however, the auditory stimuli would become object stimuli if *S* were given the task of describing the location of the source of the sound.

We may now come back to our general assumption, viz., that verticality—and also straight-ahead—is a perceptual experience which parallels a particular relation between object stimuli and organismic state. This particular relation is that of stimuli being undisturbing to the organism, i.e., not tending to introduce changes in the pertinent aspects of the organismic state.

Abstractly speaking, if we denote a physical position of a line in space by *Px*, we assume a sensory-tonic state (innervation pattern of the organism), *X*, which remains "undisturbed by" ("in harmony with," or "in tune with") stimuli issuihg from a line in the position *Px*. This relation between stimuli, *Px*, and organismic state, *X*, is reflected in the experience of the line appearing vertical. Given organismic state *X*, stimuli from a line in all positions other than *Px* will tend to induce changes in the organismic state (i.e., are disturbing to the organism); this will be reflected in an experience of perceptual tilt.

Two consequences of this conceptualization should be brought out. (*a*) With change of the organismic state from *X* to *Y* the position of the line undisturbing to the organismic state changes from *Px* to *Py;* therefore apparent verticality previously a reflection of the relation *Px-X* becomes now a reflection of *Py-Y*. One of the ways in which the organismic state may be changed is through extraneous stimulation. Thus, if by extraneous stimulation the state of the organism is changed from *X* to *Y* we expect that apparent verticality will be referred to a line in the physical position *Py* rather than *Px*. (*b*) Another assumption is that of the tendency of the organism to minimize disturbing relationships; e.g., given *Py* and an organismic state other than *Y* there is a tendency for the organismic state to change in the direction of *Y* (equilibration tendency). Such a tendency of equilibration is exemplified, in our way of thinking, by the phenomenon of figural adaptation, i.e., a tilted line appears more and more vertical with inspection (**10**).

Within this conceptual framework, we have previously diagrammed more specifically the mechanisms involved in the changes of apparent verticality due to extraneous stimulation (**6**). Diagrams of this sort are presented in Fig. 2 for both the perception of verticality and the straight-ahead.

Specific assumptions underlying the diagram are: (*a*) When maintaining a position of head tilt or head torsion to one side, counterbalancing forces ensue to the opposite side (**11**). For instance, to maintain head tilt to the left, forces to counteract gravitational pull come into play; in other instances such forces may ensue from intra-organismic righting tendencies, etc. (*b*) For a short-hand schematic characterization of different organismic states we use the term "equilibrial axis." Equilibrial axis simply denotes the distribution of forces (innerva-

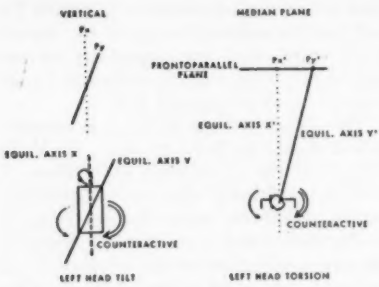

FIG. 2. Hypothetical schema. Effect of extraneous stimulation: Left head tilt and position of apparent vertical; Left head torsion and position of apparent median plane.

tion pattern). Thus, for example, when the body (head) is tilted to one side, falling is counteracted by muscular-tonic strains in the opposite direction; the changed distribution of forces is symbolically indicated by a shift of the equilibrial axis in the direction of the counterbalancing forces: because of the changes in the organismic state (from *X* to *Y*), the physical position of a line, to be perceived as vertical, has to be shifted (from *Px* to *Py*); the empirical evidence is that the line has to be tilted in the direction of the counteractive force.

In order to account for the shift occurring with respect to the median plane, we have to note that if the head is turned, there is induced a turning tendency of the rest of the body in the same direction. Evidence for such a tonic change in the trunk induced by head turning may be found in the studies by Goldstein (**1, 2**) and by Schilder (**5**); for instance, in cerebellar patients where counterbalancing is impaired the turning of the head induces turning of the trunk around the longitudinal axis (**5**, pp. 11–12). Similarly when the eyes are turned there is a tendency induced to turn the head. In normals this turning tendency is balanced by counteractive forces in the opposite direction, and in keeping with our schematization for verticality, the medial equilibrial axis is represented as shifting to the side of the counteractive force. According to our interpretation the observed positional shift of the apparent median plane opposite to head turning or eye turning is a reflection of this change in the sensory-tonic state of the organism.

The same kind of reasoning might be applied to interpreting the effect of fixation of a laterally positioned object (Exp. I). Since from our results we know that when a fixated object is placed to the right the position of the apparent median plane shifts to the right, we assume that the innervation pattern of the organism correlative with that position is similar to that under left head torsion (eyes closed) as depicted in Fig. 2. The only difference is that for object stimulation "active" forces directed toward keeping the object fixated have to be assumed to take the place of the "counteractive" forces involved in change of the organismic state due to extraneous stimulation.

In conclusion, the two experiments on the position of the apparent median plane under sidewise fixation and sidewise position of closed eyes provide further evidence on the differential efficacy of object versus extraneous stimulation previously found in the perception of verticality. In this connection it is noteworthy that Goldstein and Riese, in agreement with other investigators, have found that auditory localization is affected in opposite directions under conditions of eye turning when eyes are open compared with when they are closed; they have interpreted these effects as due to differences in behavior of the organism under shifting of the eyes toward an object versus under shifting of the eyes per se (cf. **1**, p. 216).

Finally, over and above the general statistically significant results, there were within each experiment a few individuals who showed effects opposite to the general trend. This raises the interesting question whether for some *S*s there is no clear-cut differentiation between turning the eyes toward an object and turning closed eyes (no object). Such deviations from the general trend to respond in terms of duality of stimulation possibly point to characteristic individual differences worthy of further exploration.

Summary

Two experiments were carried out to investigate (*a*) the effect of asymmetrically placed fixated objects and (*b*) the effect of head torsion and of eye turning, on the position of the apparent median plane. The methodology of pointing to a place in space that appeared straight-ahead (apparent median plane) was used in both experiments.

It was found that the position of the apparent median plane shifted in the direction of the fixated object, i.e., in the direction of eye turning; in contrast, with eyes closed, the position of the apparent median plane shifted opposite the direction of horizontal eye turning, and opposite the direction of head torsion. These effects are interpreted to be analogous to those found previously for the perception of verticality; the study therefore provides evidence for the generality of the constructs used within the framework of sensory-tonic field theory.

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EXPERIMENTS ON SENSORY-TONIC FIELD THEORY OF PERCEPTION: VII. EFFECT OF ASYMMETRICAL EXTENT AND STARTING POSITIONS OF FIGURES ON THE VISUAL APPARENT MEDIAN PLANE[1,2]

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A previous study has shown effects of eye-turning on the position of the apparent median plane ("straight-ahead") which were opposite depending on whether eye-turning was invoked to fixate a laterally placed object (object stimulation) or whether eye-turning was in the nature of postural change only, i.e., stimulation was carried out with closed eyes (extraneous stimulation). Under eye-turning while blindfolded the position of the apparent median plane shifts in the direction opposite to turning; under fixation of a laterally placed object the apparent median plane shifts relatively to the side of object placement (**6**), i.e., to the side of eye-turning.

In the present study we are concerned principally with the effects of asymmetrical horizontal extent of a figure (e.g., oblong) with respect to fixation, and of starting position, on the apparent median plane. Asymmetrical extent pertains to object stimulation, and therefore we should expect that variations in asymmetrical extent would produce variations in the position of the apparent median plane analogous to the effects previously observed under fixation of a laterally placed object (**6**).

That figures placed asymmetrically with respect to fixation affect the straight-ahead has been suggested by observations made by Roelofs (**1**). He used a homogeneously illuminated square in the dark room and asked the observer to fixate the left (right) edge of the figure, and to adjust that particular edge so that it appeared straight-ahead: when *S* fixated the right edge he had to move the square relatively more to the left; when he fixated the left edge he had to move the square relatively more to the right.

Roelofs' observations were originally of interest because we thought of them simply as a demonstration of the effect which asymmetrical light distribution has on the organism. Accordingly in our original exposition of the sensory-tonic field theory we interpreted Roelofs' observation in the following way: "These changes can be explained in terms of asymmetrical tonus loadings induced by light. In Condition A [fixation of left edge of the square] in consequence of the greater tonus on the right (induced by the light) the subjective median plane is shifted to the right, i.e., to the side of the increased tonus" (**3**, p. 97).

Our subsequent experimental studies and theoretical analysis carried out within the area of apparent verticality have led us to doubt this interpretation in terms of flux-induced tonus. We have found that at least for one dimension of space, verticality, spatial localization is affected by figural position, irrespective of flux. Thus, two experiments were designed to evaluate the

[1] This investigation was supported by a grant from the National Institute of Mental Health of the National Institutes of Health, Public Health Service.

[2] An experiment preliminary to this study was performed by Walter B. Simon (**2**); the data for the present experiment were gathered principally by Jan H. Bruell and Alvin G. Goldstein.

importance of asymmetrical placement of the figure versus flux on the location of the apparent median plane.

A third experiment dealt with another aspect of object stimulation, viz., the starting position effect. This effect, as studied previously with respect to verticality, pertains to the fact that the initial placement of a rod affects the final position in which it is seen as vertical. Here, the problem was whether analogous starting position effects occur with respect to the position of the apparent median plane.

General procedures.—All three experiments had the following apparatus and procedures in common. The tests were performed in a dark room. The *S* sat erect throughout all trials in a chair with side supports. His head was held in position by an adjustable head rest; by this device head and trunk were kept constant throughout the trials. In all three experiments luminescent test figures were used. The *S*'s task, in general, was to fixate part of the test figure, to instruct *E* to move the figures so that the fixated part appeared straight-ahead of *S*. The figure was placed at a specified distance from *S* and could be moved in small steps horizontally in the frontoparallel plane on a track. The position of the apparent median plane defined by the *S* as straight-ahead was measured in terms of deviation from the objective median plane. The objective median plane was determined by projecting the median sagittal plane of *S*'s head and body upon the frontoparallel plane. Arbitrarily, positions to the left of the objective median plane were designated by minus values; positions to the right of the objective median plane were designated by plus values.

Experiment I

In this experiment the efficacy of asymmetrical extent in relation to flux was evaluated by utilizing a test figure with minimal flux.

Procedure.—Three equidistant pin points of light arranged horizontally, and placed 10 ft. from *S*, served as the test figure. The total length of the test pattern was 20 cm. Specifically, the task of *S* was to instruct *E* how to move the test pattern so that the fixated part appeared straight-ahead. The task was carried out under two conditions: (*a*) The three-dot pattern was placed so that its right dot was in the objective median plane; this dot was fixated. (*b*) The pattern was placed so that its left dot was in the objective median plane; here, the left dot was continuously fixated. Thus in the first test condition the pattern extended asymmetrically to the left of the objective median plane, and in the second condition asymmetrically to its right.

Twenty *S*s were tested under both experimental conditions. For half of the *S*s Cond. *b* followed Cond. *a;* for the other half the sequence was reversed.

Results.—Under the first test condition, viz., "right-dot fixation," the mean position of the apparent median plane was + .3 cm.; under the second test condition, viz., "left-dot fixation," the mean position of the apparent median plane was + 9.4 cm. The difference in position of the apparent median plane under the two test conditions, 9.1 cm., was significant beyond the .01 level of confidence.

Thus, when the test pattern extends to the right of fixation the apparent median plane is shifted relatively more to the right, compared with the pattern extending to the left of fixation. From this experiment we may conclude that the general result found by Roelofs with asymmetrically placed luminous squares also obtains when the flux from the test pattern is minimal.

This experiment suggests, then, that an object property, viz., asymmetrical extent irrespective of flux, is a significant factor in the observed displacement of the apparent median plane. This suggestion was tested more directly by the following experiment.

Experiment II

Here the efficacy of flux versus asymmetrical extent was studied by the use of figures of the same shape, one a solid luminescent square and the other an outline square. In accordance with the previous experiment we should expect that asymmetrical extent significantly affects the position

of the apparent median plane, irrespective of great differences in total flux.

Procedure.—Two squares, 20 × 20 cm., were used as test figures. One square was solid, i.e., the whole surface was covered with luminescent paint. The other figure was an outline square, i.e., only the contour was luminescent. Each square was placed in two positions with respect to the median plane, making a total of four test conditions (Fig. 1):

(*a*) "Solid Left": right edge fixated and in objective median plane; figure extends to left of the objective median plane.
(*b*) "Solid Right": left edge in objective median plane; figure extends to right.
(*c*) "Outline Left": right edge in objective median plane; figure extends to left.
(*d*) "Outline Right": left edge in objective median plane; figure extends to right.

Under all test conditions the fixated edge was placed initially in the objective median plane, 200 cm. in front of *S;* the *S* again had the task to instruct *E* to move the figure so that the fixated edge appeared straight-ahead.

A replicated 4 × 4 latin-square design was used. Three men and three women were tested in each sequence, making a total of 24 *Ss*.

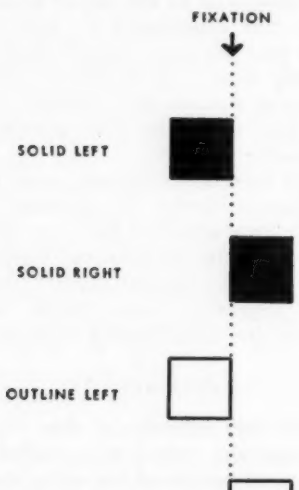


FIG. 1. Experiment 2 test conditions

Results.—The results are presented in Table 1. It can be seen that with the "Solid-Left" square, the apparent median plane was shifted relatively to the left and with the "Solid-Right" square the apparent median plane was shifted relatively to the right. The mean positions of the apparent median plane for women are −7.4 cm. and +2.5 cm., respectively; and for men −4.0 cm. and +.5 cm., respectively. The differences in the shift of apparent median plane are significant beyond the .01 level.

The same relationships hold for the outline figures, i.e., the "Outline-Left" square shifted the position of the apparent median plane to the left (−6.2 cm. for women; −3.1 cm. for men); the "Outline-Right" square shifted the position of the apparent median plane to the right (+1.8 cm. for women; +1.9 cm. for men).

On the other hand, there is no evidence of a significant effect of flux: the position of the apparent median plane does not differ significantly for "Outline-Left" square and "Solid-Left" square; there is also no evidence of a significant difference for "Outline-Right" versus "Solid-Right" square.

EXPERIMENT III

The influence of the position of a rod at the beginning of a trial (starting position) on the final position in which it is perceived as vertical was systematically studied in a previous investigation (**4**): the apparent vertical was found to be relatively close to the position in which the rod was initially set.

Analogous to these findings on verticality, the following hypothesis concerning the median plane was tested:

The position of the straight-ahead (apparent median plane) is a function of the initial placement of a test figure:

TABLE 1

POSITION OF APPARENT MEDIAN PLANE: ASYMMETRICAL PLACEMENT VERSUS FLUX

F Tests

Source of Variation	Women				Men		
	df	Mean Square	*F*	*p*	Mean Square	*F*	*p*
Individuals	11	44.44	—	—	23.61	—	—
Sequence	3	28.92	<1.00*	>.05	3.02	<1.00*	>.05
Individuals within sequence	8	50.26	2.55	<.05	31.33	4.18	<.01
Conditions	3	327.14	16.62	<.01	95.59	12.75	<.01
Ordinality	3	7.11	<1.00	>.05	.98	<1.00	>.05
Square uniqueness	6	5.45	<1.00	>.05	2.84	<1.00	>.05
Error	24	19.68			7.50		
Total	47						

t Tests† (Mean Differences)

Conditions	Means (Cm.)	SL	OR	SR	Means (Cm.)	SL	OR	SR
Outline Left (OL)	−6.2	1.2	8.0‡	8.7‡	−3.1	.9	5.0‡	3.6‡
Solid Left (SL)	−7.4	—	9.2‡	9.9‡	−4.0	—	5.9‡	4.5‡
Outline Right (OR)	+1.8		—	.7	+1.9		—	1.4
Solid Right (SR)	+2.5			—	+0.5			—

* Tested against individuals within sequence.
† The standard error of the difference used in computing *t* was derived from the error variance ($df = 24$) indicated in the *F* table.
‡ $p < .01$.

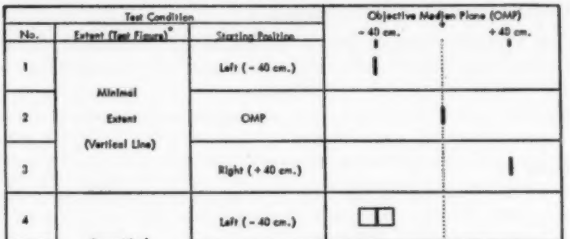
other things being equal, the position of the straight-ahead will be relatively closest to the position in which the test figure is set initially in the visual field; i.e., if a test figure is placed to the left of the objective median plane, in the objective median plane, or to the right of the objective median plane, the straight-ahead will be shifted respectively more to the left, more toward the center, more to the right.

Procedure.—Starting-position effects were studied with test figures which differed with respect to asymmetrical extent. Four test figures were used: (*a*) Vertical line (minimal horizontal extent): a luminescent vertical line 20 cm. high and .5 cm. thick was fixated. (*b*) Double square (extent symmetrical): a double square with its symmetry axis fixated—this figure was made up of two 20 cm. luminescent squares placed next to each other so that the test figure was actually a rectangle 40.5 cm. wide and 20 cm. high, broken by a dark strip .5 cm. wide in the symmetry axis. (*c*) Square left (left asymmetrical extent): the right edge of the square was fixated; i.e., the test figure extended to the left of fixation. (*d*) Square right (right asymmetrical extent): the left edge of the square was fixated, i.e., the test figure extended to the right of fixation.

The part or edge of each of these four test figures to be fixated was placed in three starting positions: 40 cm. to the left of the objective median plane; in the objective median plane; and 40 cm. to the right of the objective median plane. Under all test conditions the test figure was 200 cm. in front of *S*. Here, again, *S* had the task to instruct *E* to move the figure so that the fixated part appeared straight-ahead.

The experimental design thus provided variation of three starting positions under four conditions of figural extent. The 12 conditions used are diagrammed in Fig. 2. A 12 × 12 latin-square design was employed. One male and one female were tested in each of the twelve sequences making a total of 24 *Ss*.

Results.—The analysis of variance is summarized in Table 2. Before discussing the effects of starting position



* The flanked edge or part of test figure is indicated by a thicker line

FIG. 2. Experiment 3 test conditions

and asymmetrical extent in detail, it may be noted that *F* for experimental conditions is significant beyond the .01 level of confidence.

TABLE 2

EFFECT OF STARTING POSITION AND ASYMMETRICAL EXTENT ON THE POSITION OF THE APPARENT MEDIAN PLANE

		F Tests		
Source of Variation	*df*	Mean Square	*F*	*p*
Individuals	23	615.37	—	—
a. Sex	1	158.57	<1.00*	>.05
b. Sequence	11	788.98	1.63*	>.05
c. Individuals within sequence	11	483.29	5.74	<.01
Conditions	11	1587.51	18.87	<.01
Ordinality	11	58.17	<1.00	>.05
Square uniqueness	110	76.98	<1.00	>.05
Error	132	84.15		
Total	287			

* Tested against individuals within sequence.

The mean positions of the apparent median plane and mean differences are presented in Table 3. The results are in accord with expectation: the position of the apparent median plane was displaced in the direction in which the test figure was placed at the beginning of the trial; this effect holds for each of the four conditions of asymmetrical extent, viz., minimal extent (Vertical Line), symmetrical extent (Double Square), left extent (Square Left), and right extent (Square Right). Left, center, and right starting positions differ significantly with respect to each other within each of the four conditions of extent.

The data also provide confirmatory evidence for the effect of asymmetrical extent which has already been demon-

strated in Exp. I and II, i.e., the shift of the apparent median plane away from fixation and toward the side to which the figure extends. This may be seen from the results obtained for Cond. 8 and 11, where starting position was minimized but asymmetrical extent differed. In Cond. 8 (Square Left) the right edge was fixated and initially placed in the objective median plane, i.e., the figure extended to the left; in Cond. 11 (Square Right) the left edge was fixated and initially placed in the objective median plane, i.e., the figure extended to the right. The mean position of the apparent median plane under asymmetrical extent to the left of fixation is −5.3 cm. and under asymmetrical extent to the right of fixation is +3.0 cm. The difference, 8.3 cm., is significant beyond the .01 level of confidence.

One further feature of the results may be mentioned; this pertains to those test conditions where starting position and asymmetrical extent are put into simultaneous operation, viz., Cond. 7, 9, 10, and 12. The position of the apparent median plane shifts farthest to the left under simultaneous operation of left starting position and left asymmetrical extent (Cond. 7), farthest to the right under simultaneous operation of right starting position and right asymmetrical extent (Cond. 12), and in between these extremes when starting position having an effect in one direction operates simultaneously with asymmetrical extent having an effect in the opposite direction (Cond. 9, 10).

Discussion

The results of Exp. I and II demonstrate that the apparent median plane is affected in a specific way by the asymmetrical extent of test figures: a test figure which extends asymmetrically to

TABLE 3

Effect of Starting Position on the Position of the Apparent Median Plane

Means, Mean Differences, *t* Tests*

Test Condition			Mean Position of Apparent Median Plane (cm.)†	Mean Differences											
No.	Test Figure	Starting Position		1	2	3	4	5	6	7	8	9	10	11	12
1	Vertical Line	Left	−11.4	—	9.4	13.8	2.7	9.8	18.0	3.4	6.1	12.9	1.4	14.4	19.2
2		OMP‡	− 2.0		—	4.4	12.1	.4	8.6	12.8	3.3	3.5	10.8	5.0	9.8
3		Right	+ 2.4			—	16.5	4.0	4.2	17.2	7.7	.9	15.2	.6	5.4
4	Double Square	Left	−14.1				—	12.5	20.7	.7	8.8	15.6	1.3	17.1	21.9
5		OMP	− 1.6					—	8.2	13.2	3.7	3.1	11.2	4.6	9.4
6		Right	+ 6.6						—	21.4	11.9	5.1	19.4	3.6	1.2
7	Left Extent	Left	−14.8							—	9.5	16.3	2.0	17.8	22.6
8		OMP	− 5.3								—	6.8	7.5	8.3	13.1
9		Right	+ 1.5									—	14.3	1.5	6.3
10	Right Extent	Left	−12.8										—	15.8	20.6
11		OMP	+ 3.0											—	4.8
12		Right	+ 7.8												—

* The standard error of the difference used in computing *t* was derived from the error variance ($df = 132$) indicated in the *F* table (Table 2). Mean differences required for significance (one-tailed test): 4.3 ($p = .05$); 6.2 ($p = .01$).

† Positions to the left of the objective median plane are designated by "−" values; positions to the right of the objective median plane are designated by "+" values.

‡ Objective median plane.

the left of the fixation plane results in a shift of the straight-ahead or apparent median plane to the left; a test figure which extends asymmetrically to the right of the fixation plane results in a shift of the apparent median plane to the right. These results are, of course, an expression of the initial perception of *S*s who see an oblong asymmetrically extended, e.g., to the left of fixation, as displaced to the right, i.e., in a more symmetrical position.

The observed effect does not warrant, as we originally thought, an interpretation in terms of light-induced tonus; the factor of primary importance, rather, appears to be that of a figural property, asymmetrical extent. Therefore, within the framework of the sensory-tonic field theory of perception these effects will have to be interpreted in terms of relationships obtaining between object stimuli (configurational arrangement) and organismic state.

Whether or not flux may have a significant effect independent of asymmetrical extent is a matter for further experimentation. We should, however, note that if systematic variation of flux should give differential effects, there still remains the difficulty of interpretation. It may be questioned whether such effects were a function of flux per se, or a function of flux indirectly contributing to the configurational aspect of objects, such as contour strength, figure-ground distinctiveness, etc.

As we see it, an interpretation in terms of relations between object stimuli and organismic state also will have to be invoked with respect to the results of Exp. III on starting position. There it was found, analogous to the starting position effects pertaining to the perception of verticality, that the straight-ahead (apparent median plane) is shifted toward the position in which the test object is set at the beginning of a trial.

We have viewed the starting position effect in the studies of verticality in descriptive terms as a tendency toward "verticalization" of a tilted line. One can also express the starting position effect for the median plane in descriptive terms, i.e., a line asymmetrically placed with respect to the objective median plane tends to appear in a straight-ahead position (symmetrization). In accordance with the tenets of the sensory-tonic field theory we have interpreted these tendencies towards "verticalization" and "symmetrization" as expressions of equilibration trends of the organism in response to object stimuli.

We may briefly review the general assumptions which underlie the notion of equilibration as discussed more fully in the foregoing paper of this series (6). The primary assumption is that the apparent vertical and apparent median plane are experiences which parallel particular relations obtaining between stimuli from an object and organismic state. The particular relation is that of the stimuli being "undisturbing" to the organism, i.e., not tending to induce changes in the pertinent aspects of the organismic state. Our further assumption is that the introduction of asymmetrically placed stimuli invokes a change in the organismic state; this new organismic state will then be less disturbed by the stimuli which were disturbing to the organismic state before the change took place. We have referred to stimuli of minimal disturbance to the organismic state as being "in tune with" or "in harmony with" the organism. Such changes of the organismic state toward harmonization reflect themselves perceptually in the shift of the position of the apparent median plane, e.g., a line previously experienced in a lateral position now is experienced as being closer to straight-ahead.

This kind of reasoning can also be applied to the interpretation of the effect of asymmetrical extent on the apparent median plane. The tendency to see an asymmetrically extended figure in a more symmetrical position with respect to the body may be conceived of as a manifestation of a tendency to "harmonize" stimuli-organism relationships by changing the organismic state. Thus, both for figures which extend asymmetrically to the left or to the right of fixation (asymmetrical extent), and for points or lines

which are placed asymmetrically with respect to the objective median plane (starting position), the mechanism is assumed to be the same, viz., a trend toward equilibration.

Summary

Three experiments were carried out concerned with the shifts of the position of the apparent median plane, defined as the straight-ahead. It was found that a test figure extending asymmetrically to the left of fixation produces a shift of the apparent median plane relatively to the left compared with a test figure extending asymmetrically to the right of fixation. The effect of asymmetrical figural extent has been found to be significant irrespective of the degree of flux emanating from the figural surface. Furthermore, there was evidence for starting position effects, analogous to those previously found in studies on verticality; i.e., other things being equal, the position of the straight-ahead (apparent median plane) is relatively closest to the position in which a line is placed in the visual field; if a line is initially placed to the left of the objective median plane, in the objective median plane, or to the right of the objective median plane, the straight-ahead is shifted respectively more toward the left, more toward the center, more toward the right.

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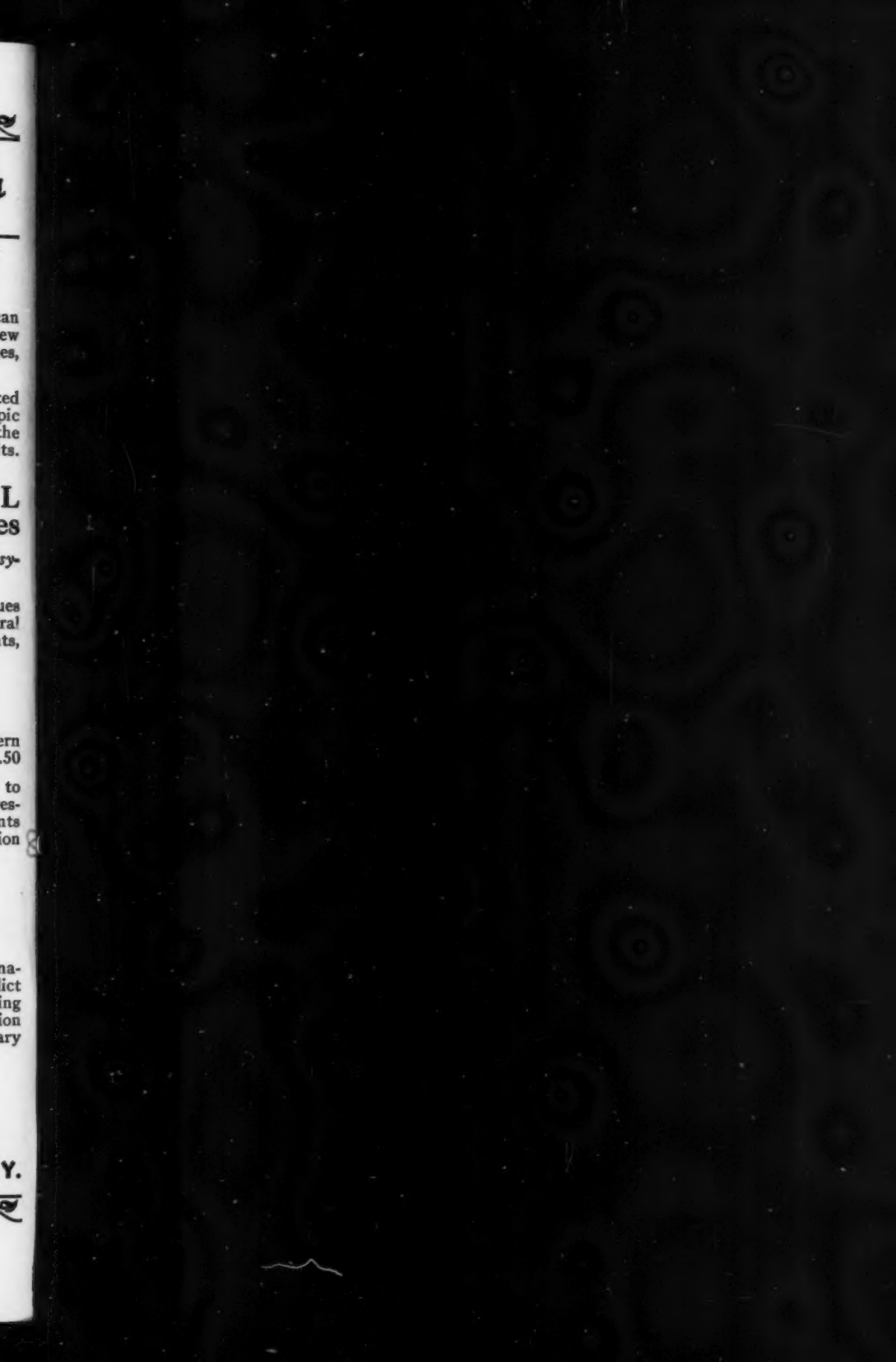
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